# G.E.C. Journal

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**The late Max John Railing, M.I.E.E.**
*(from a painting by Harold Knight, R.A.)*

# Max John Railing.

MY lifelong friend and colleague, Max Railing, has departed from our midst. By his death the Company has suffered its biggest blow since it lost its first Chairman, my predecessor, thirty-two years ago. Every one of us has lost in him a good friend and many of us our best friend. Mr. Railing, or, better, "M.R.", as he loved to be addressed by us, was at all times a tower of strength in the building up of the G.E.C. His love of work, his conscientious attention to duty, his clear head, his great ability as an administrator and industrialist were outstanding characteristics. These, combined with his kindness towards all who approached him with an honest purpose, were an inspiration to all G.E.C. men, and proved a powerful force in shaping the fortunes of our Company. By the confidence he inspired in the many of our staff and workers who came into contact with him, he did much to create that family spirit in the G.E.C. of which we are all so proud.

"M.R." entered business just fifty years ago by joining the then young staff of the G.E.C. His great ability and his love of hard work were soon apparent and he was singled out by me for quick promotion until he arrived at the position of Joint Managing Director and Vice-Chairman of the Company which now employs over 50,000 people.

Though mainly concerned during the whole of his life with helping to build up the G.E.C. his influence transcended the borders of this Company. He believed in adding to its strength and security by co-operation with his colleagues in the industry. His upright character and the confidence he inspired assisted him in these efforts and the result is bearing great fruit in this time of emergency when Government Departments need the efforts of industry as a whole rather than those of the selected few. He was of a retiring disposition and evaded the limelight, yet his success permeated to the outside world. He filled the position of Vice-President of the British Electrical and Allied Manufacturers' Association and sat for several years on the Board of Trade Advisory Council. He also took an interest in civic affairs and was Master of the Worshipful Company of Playing Card Makers.

Mr. Railing was accessible to everybody, and the well-being of the members of our staff and the workers in the factories was ever uppermost in his mind. He gave of his best all his life and his work will endure.

# Lightning Arresters.

By W. WILSON, D.Sc., B.Eng., M.I.E.E..
Development Department, Witton Engineering Works.

THERE has been a great advance in both the theory and practice of lightning protection during the past ten to fifteen years. In the first place, the nature and behaviour of thunderstrokes are now understood very much more thoroughly than was formerly the case; and second, electrical engineers have employed this more exact knowledge in the design and calculation of efficient arresters. Ineffective devices have been abandoned, and apparatus has been produced which, though simpler and less costly than the earlier types, can be relied upon to play its allotted part in the predetermined manner.

Few branches of the industry have not reaped some benefit from the new developments. Supply engineers are probably the most concerned, since their work can now be carried on with a much lower risk of interruption. Apart from the greater reliability of the main arresters, increased security can be obtained by locating units at special points where experience has shown that troublesome surges are to be expected. Designers and manufacturers of a wide range of plant, including overhead lines, transformers, machines and switchgear, can turn out their products with the greater confidence now that the possible over-voltage to which they may be subjected can in the great majority of cases be limited to a definite value. Finally, maintenance engineers appreciate the advantages of a device which requires an absolute minimum of attention. A brief description of the modern arrester will therefore be of interest.

## LIGHTNING INVESTIGATIONS.

Many factors have contributed to the present greatly increased knowledge of lightning and its behaviour. The comprehensive theory of Sir G. C. Simpson, described in his epoch-making address before the Royal Society published in 1926,* provided for the first time a complete explanation of the origin and properties of atmospheric electricity; and though the paper aroused wide-spread controversy and the theory has been modified in some of its details, its main structure is now generally accepted. Professor Schonland's prolific researches with the Boys rotating-lens camera, carried out in the fertile atmosphere of South Africa, have revealed the full mechanism of the lightning stroke. The surge generator has enabled lightning to be produced artificially, of steadily increasing voltage, quantity and steepness of wave-front; while the cathode ray oscillograph has, more than any other instrument, assisted the investigation by faithfully recording the shapes of the voltage and current waves, and showing the effect of the various protective devices.

* Proceedings of the Royal Society. A.1926, Vol. III., p. 56.

## PROTECTIVE REQUIREMENTS.

It is not a difficult matter to define the duty required of an arrester, as an almost exact mechanical analogy exists in the steam safety valve. When the pressure is normal, this device permits no relief current of steam to pass at all, or in other words its resistance is infinite; but as soon as the normal boiler pressure is exceeded, the valve lifts and permits a large flow to escape, implying an automatic and considerable decrease of resistance. This valve action is well known as doing all that is required for the steam boiler, its resistance falling to such a value that all the surplus steam which can be generated is passed out without requiring a pressure rise of more than a few per cent.

The electrical case is more severe than its steam prototype in one important respect, namely that the overpressure takes the form of a sudden surge of many times the normal value, reaching its crest value in one or two microseconds at most. It is therefore indicated that the valve action should if possible be more pronounced than in the steam case, if equivalent results are to be secured. Actually, however, the insulation of electrical equipment is designed to withstand over double the normal voltage, since it is possible for the line pressure to rise to something approaching this value through faulty governor action. The present standard sparkover voltage for an arrester unit connected between line and neutral is $2\frac{1}{4}$ times the line (between-phase) voltage. But it is none the less essential that a great reduction in resistance must occur immediately the above limit has been overstepped.

Since, moreover, the onset of the surge is so sudden, the action of the arrester must be even more rapid if the crest voltage, or any considerable fraction of it, is to be intercepted before it has had time to impose itself upon the equipment protected.

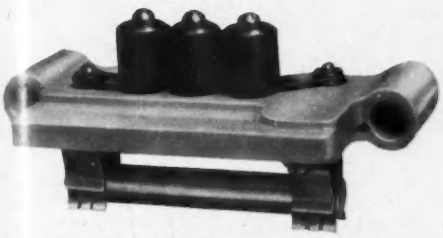


**Fig. 1.—Tension limiter for 1,100 volt circuits, largely superseded by the type shown in fig. 2.**

## EARLIER TYPES OF ARRESTER.

The requirements as regards valve-action may be contrasted with the make-up of most early arresters, which nearly all incorporated a fairly considerable fixed resistance in series with some kind of spark gap. For example, a common value of resistance for circuits of about 3·3 kV was 50 ohms. This would involve a voltage rise of half a million volts during the passage of a 10,000 ampere surge, which is quite an ordinary relief current for a present day arrester, and is now unattended by a dangerous peak voltage of similar origin.

In the models referred to, the spark gap does actually function as a valve as far as the release of the current is concerned, but unfortunately the action is not reversible, on account of the breakdown of the air insulation in the gap through ionisation. Hence the resistance must be added to enable the gap to break the follow current, which is forced through the ionised space by the line voltage after the disappearance of the surge. The various types of arrester differed chiefly in the nature of the spark gaps, those best known being the horn-gap, "non-arcing" roller gap, and discharge tube. A typical example of these was the tension limiter, belonging to the roller gap type, which is illustrated in fig. 1.

Following the above arresters, though for many years sharing the field with them, was a type in which the place of the resistance was taken by a chemical material having the power of breaking down from insulator to conductor when a certain voltage was exceeded, and re-forming instantaneously as soon as the voltage returned to normal. An air-gap was still necessary, but in each case there were also a number of similar cells in series, giving a discharge voltage of about 300 volts per cell. The two chief materials employed were aluminium oxide immersed in a liquid electrolyte, and lead peroxide in the form of a paste. These devices possessed a true valve action, but suffered from the disadvantages of relatively high cost and large bulk, besides requiring a certain amount of maintenance.

## CHOKING COILS.

Mention has been made of two separate parts of early arresters, namely the spark gap to discharge the surge current, and the resistance to suppress the follow current. Until about ten years ago, however, a third component was considered essential, in the form of an inductance connected between the arrester and the equipment protected. It was thought that the high frequency discharge supposed to constitute a lightning surge would be turned back by this choking coil and forced to flow to earth through the arrester.

One of the first investigations carried out by the cathode ray oscillograph when it was applied to industry was an examination of the lightning discharge and its effect on a choke. The tests proved that the latter possessed insufficient inductance to produce any useful limitation of the surge current, but on the other hand the actual inductance is able to react with the self-capacity of the equipment

**Fig. 2.—Low voltage surge valve arrester, type N, with cover removed.**

to form a resonant circuit, superposing an oscillation upon the original wave that can nearly double the crest voltage. This use of the choking coil has, therefore, been generally discontinued.

## CERAMIC VALVE.

The most recent type of arrester, exemplified by the G.E.C. surge valve, is based upon a material that not only has a highly developed valve characteristic, but is also a robust and durable furnace product having remarkably

permanent characteristics and compact proportions. It is, strictly speaking, not at all new in principle, for arresters of the same general form were applied to low voltage circuits about the end of last century; but the material then used was of insufficient electric strength to withstand considerable surge voltages and currents.

Some twelve years ago the Witton Development Laboratory undertook an investigation which resulted in a surge valve with much improved characteristics, for not only did its resistance fall very steeply as the applied voltage rose above the normal value, but its mechanical and electrical strengths were greatly superior to those of the old material. The great difficulty in its production was to secure resistance values that were even approximately uniform for the various units. Batch after batch of discs were made up, by methods embodying closer and closer control of the variables in the baking process, before the performance of the different units came near to complying with the limits that had been agreed as desirable.

Finally a consignment was assembled having characteristics which were the best that could be then attained, but fell considerably below what had been attempted. A large proportion of these arresters was sent to fulfil an order in a part of India that was noted for the

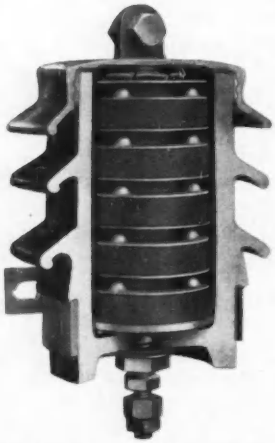


**Fig. 3.—Sectional view of high voltage surge valve arrester, type M.G.**

violence and frequency of its thunderstorms. Very soon after these had been installed, a particularly devastating storm occurred. Subsequent reports showed that while damage had been caused all over the district, the circuits protected by the new surge valve models had emerged unharmed. It was therefore clear that a really effective design had been produced.

So far, the arresters that had been designed were exclusively low voltage models, intended

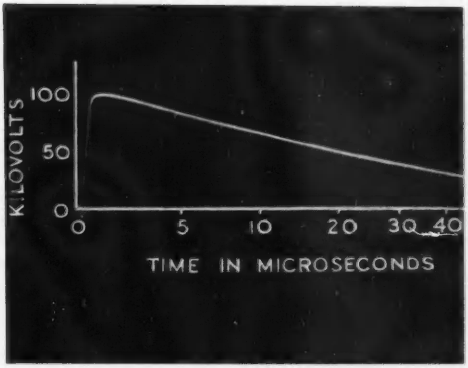



**Fig. 4.—Example of "lightning" surge, 0.5/20.**

for protecting circuits up to 440 volts; although subsequent tests showed them to be suitable for 600 volts D.C. and 1,100 volts A.C. However, the performance of these initial units indicated that the same principle would hold good for higher voltages, and designs were therefore produced successively for protecting circuits having rated voltages of 2·2, 3·3, 6·6 and 11 kV. Again the results were successful, and development continued in the upward direction until just before the outbreak of hostilities, when the arresters ordered for the British Grid were made up and installed, protecting 132 kV earthed neutral transmission lines and substation equipment. Like the initial models, these last have functioned since their installation without any complaint.

As with any other resistance units, the current carrying capacity depends upon the cross section, and the voltage rating upon the length. A diameter of 3¾ins. has been standardised as the best all-round size for G.E.C. elements, the length of each being ¾in. This will deal appropriately with a line voltage of 1,100, and therefore the number of surge-valve discs used for a given system is calculated by dividing the line potential in kV by 1·1 if the neutral is insulated or earthed through an impedance, and further multiplying by 0.8 when it is earthed directly. A high speed air-gap unit, of the sphere and plate type arranged four in parallel, is provided for every valve-disc, the whole stack

being built up of discs and gap elements alternately; its use being solely due to the advisability of the resistance being infinity for all possible values of the working line voltage.

The low-voltage units, containing a single

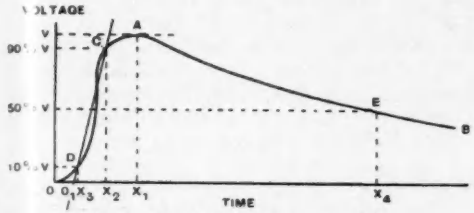



Fig. 5.—Standard impulse wave, 1/50.

disc, have a slightly different arrangement from the higher-voltage multi-disc patterns. As shown in fig. 2, the single disc has a raised rim on each side, and is located and held in place by means of a central hole. The gap is also a single one mounted on the centre-line, and seen at the top of the illustration. All other patterns are contained in an enclosure of high quality porcelain, a section of a typical model being seen in fig. 3. Since the presence of damp must be rigorously avoided, the enclosure must be either well ventilated or hermetically sealed; and the latter alternative has been adopted. The metal top-cap is held in place by insulator cement, but the air-tight seal is an independent enclosure within this, and is designed to exclude the external atmosphere completely and continuously under all conditions.

## NATURE OF LIGHTNING SURGE.

The large amount of scientific information that has been rendered available during recent years has enabled the design of the lightning arrester to be closely correlated with the phenomena it is intended to counteract, and the performance of any particular model can hence be predicted with a fair degree of certainty. The action of the device will therefore be traced out, starting from the arrival of the lightning impulse.

When a transmission line is struck by lightning at a given point, the conductor in the vicinity of that point is charged to a high potential, the charge then dissipating itself by travelling along the conductor with the speed of light. This condition is in fact analogous to that produced when a volume of water is suddenly emptied on to a flat surface. The travelling wave of electricity constitutes a surge having a steep wave-front and a gradually falling tail, as shown by the actual example of such a surge in fig. 4. This was produced by the impulse generator at Witton and recorded by a high speed cathode ray oscillograph. It resembles the natural lightning surge very closely. The two portions will be seen to be equivalent to the sudden charge of a condenser and its subsequent discharge through a resistance; and since both are exponential curves, the equation of the whole may be written

$$e = E_0\left\{\varepsilon^{-\alpha t} - \varepsilon^{-\beta t}\right\}$$

For testing and rating purposes it is necessary to employ a standard wave which will represent the most severe conditions likely to occur in practice, and accordingly the wave shown in fig. 5 has been adopted by the British Standards Institution in British Standard Specification No. 923. The rising portion from $O$ to $A$ is called the "front" and is reached in 1 microsecond, while the falling portion from $A$ onwards is the "tail," the time $OX_4$ required to reach half the peak value being 50 microseconds. This wave is accordingly designated by the symbol 1/50.

Such an impulse voltage possesses two features that must be borne in mind in the present connection. In the first place, since time is required to cause breakdown, any insulation will withstand a higher voltage for these short periods than can be resisted continuously; the relation between the two values being termed the "impulse ratio." Secondly, a steep-fronted wave such as has been described will concentrate a heavy voltage drop upon the end turns of a winding. It is therefore possible to reduce the risk of damage not only by cutting off the top of the

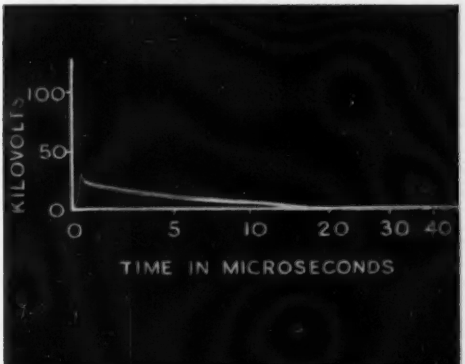



Fig. 6.—The same surge as in fig. 4, but with surge valve arrester connected.

wave so as to limit the applied voltage, but also by decreasing the angle of the wave front.

It is the first of the above functions that is fulfilled by the arrester, the effect of which is exemplified by fig. 6. This shows the same surge as in fig. 4, but with its height reduced by a surge-valve arrester connected to the

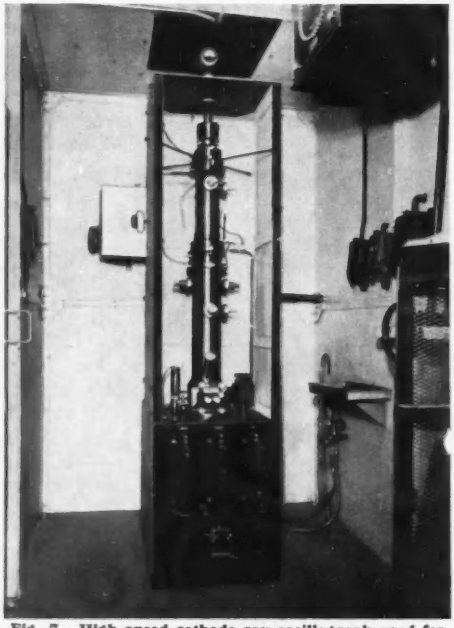


**Fig. 7.—High speed cathode ray oscillograph used for lightning arrester tests.**

line. The foregoing oscillograms were taken by the high power cathode ray oscillograph shown in fig. 7.

Front angle reduction is carried out automatically by the resistance and corona losses of the line conductors as the wave travels away from its source. Surges originating near a station or substation would, however, still be steep-fronted, and are frequently catered for by means of condensers connected to the line where it enters the building. Alternatively, the last few hundred yards of line are often run underground for the same purpose, partly because it is then immune from lightning as far as that length of feeder is concerned, but largely because the cable constitutes an effective capacity to earth.

The steepness of front decides the rate at which the surge is applied to an arrester under test, and which is specified to be 100 kV per microsecond per 11 kV of rating. As regards surge current, the rate of increase is fixed as an average of 150 amps. per microsecond to a crest value of 1,500 amps., followed by a decrease to half crest value in not less than 10 microseconds. This cycle must be carried out 30 times at 1-minute intervals as a proof of durability. It is also customary to require that the arrester shall pass successfully a surge current of at least 10,000 amps. Since the apparatus that comply with the above tests will give satisfactory service in the field, the conditions laid down may be assumed to be representative of the effects produced by a severe lightning surge.

## PERFORMANCE OF G.E.C. ARRESTER.

The valve characteristic of the G.E.C. resistance material is due to the current which it permits to flow increasing at a very much greater rate than the applied voltage. If the voltage is doubled, the current becomes about twenty times as great. Changes in the composition and methods of manufacture enable the value of this multiplier to be varied, but the above can be taken as a typical figure. Since the rate of increase is continuous, the relief current is able to reach very large values before the excess voltage has approached the danger point. For example, multiplying the voltage by 4 brings about an increase in the current to 400 times the original figure, and so on. As shown later in fig. 9, impulse tests have been carried out up to about 16,000 amps., at which the principle still holds good.

A further valuable feature in connection with the relief current is that the resistance variation is immediate. If the cathode ray oscillograms in figs. 4 and 6 are compared, it will be seen that the reduction of the wave-front voltage occurred after a delay of only about 0·2 microsecond, and was instrumental in limiting the instantaneous voltage to only 30 kV. If there were any considerable delay, such as for example 0·01 second, the stress would be imposed upon the circuit insulation for nearly the whole of that period, and breakdown would in all probability occur.

It is important that the negative resistance effect should be carefully distinguished from that due to temperature, which naturally takes time to produce its result. Incidentally, the surge-valve material does possess a negative temperature coefficient, such as to cause a current increase of 0·6 per cent per 1 deg. C.

Since the resistance/voltage variation is an exponential one, it can most conveniently be recorded by means of exponential equations or logarithmic curves. The following relationships hold between voltage, current and

resistance; representative values of the various indices and the constant C being given:

$$= aE^b; \text{ (where } b = 4) \cdot \quad (1)$$

$$R = kE^{-(b-1)}; \text{ (where } b - 1 = 3) \quad (2)$$

$$RI^n = C; \text{ (where } n = (b-1)/b = 0{\cdot}75, \text{ and } C = 800) \cdot \quad (3)$$

Here $I$, $E$ and $R$ are the current, voltage and resistance respectively, and $a$, $k$ and $C$ are constants. The first two equations give directly the variations of current and resistance with voltage, while the third is derived from the first two by elimination of $E$, and is a convenient form in that the constant on the right is the resistance in ohms for a current of 1 amp.

Exponential curves are easy to plot on log-log paper, upon which they become straight lines; and the volt-ampere characteristics of the range of G.E.C. arresters, from the 250-volt D.C. single-disc unit to the 132 kV models, can hence be shown on the one diagram, forming fig. 8. These consist of graphs corresponding to equation (1), connecting relief current with applied voltage; they are taken under steady conditions. They show graphically the very great fall in resistance and increase in current for comparatively moderate voltage rises. The variation of resistance is particularly rapid for the 250 volt curve, the currents at 500, 1,000 and 2,000 volts being 1, 25, and 630 amps.; and the values of $b$, $n$, and $C$ being 4·6, 0·78 and 500 respectively. Even this very pronounced valve action is not by any means the last word, as investigation of the surge-valve material is the subject of continuous research, and means have been found for increasing the effect considerably.

One of the principal requirements of the

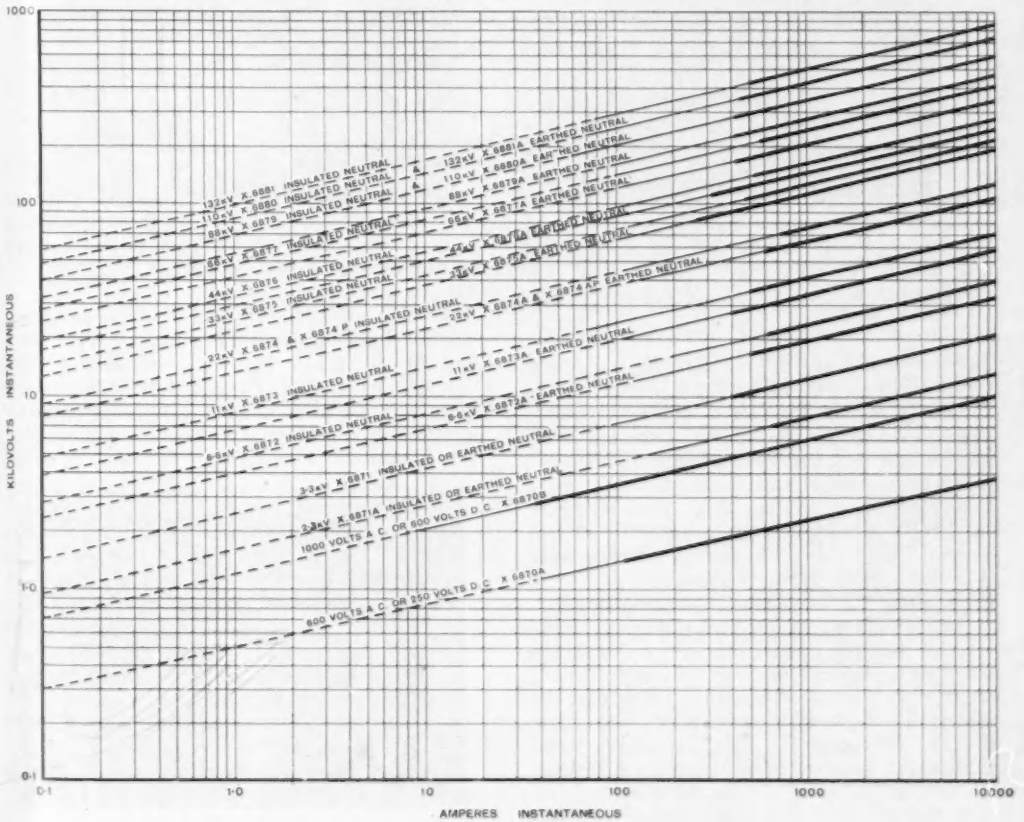

KILOVOLTS INSTANTANEOUS
AMPERES INSTANTANEOUS
1000
100
10
1·0
0·1
0·1
1·0
10
100
1000
10000
132kV X 6881 INSULATED NEUTRAL
110kV X 6880 INSULATED NEUTRAL
88kV X 6879 INSULATED NEUTRAL
66kV X 6877 INSULATED NEUTRAL
44kV X 6876 INSULATED NEUTRAL
33kV X 6875 INSULATED NEUTRAL
22kV X 6874 & X 6874 P INSULATED NEUTRAL
11kV X 6873 INSULATED NEUTRAL
6·6kV X 6872 INSULATED NEUTRAL
3·3kV X 6871 INSULATED OR EARTHED NEUTRAL
2·2kV X 6871A INSULATED OR EARTHED NEUTRAL
1000 VOLTS A.C. OR 600 VOLTS D.C. X 6870B
600 VOLTS A.C. OR 250 VOLTS D.C. X 6870A
132kV X 6881A EARTHED NEUTRAL
110kV X 6880A EARTHED NEUTRAL
88kV X 6879A EARTHED NEUTRAL
66kV X 6877A EARTHED NEUTRAL
44kV X 6876A EARTHED NEUTRAL
33kV X 6875A EARTHED NEUTRAL
22kV X 6874A & X 6874 AP EARTHED NEUTRAL
11kV X 6873A EARTHED NEUTRAL
6·6kV X 6872A EARTHED NEUTRAL

**Fig. 8.—Volt-ampere characteristic of G.E.C. surge valve arresters. For rising voltage, arresters discharge at the beginning of the thick continuous line of the curve, and for falling voltage they cut off at the lower end of the thin continuous line.**

disc material is high mechanical and electrical strength. Functioning as it does, first as an insulator with a high voltage impressed upon it, and immediately afterwards as a conductor carrying thousands of amperes, quite exceptional properties are needed if it is to fulfil

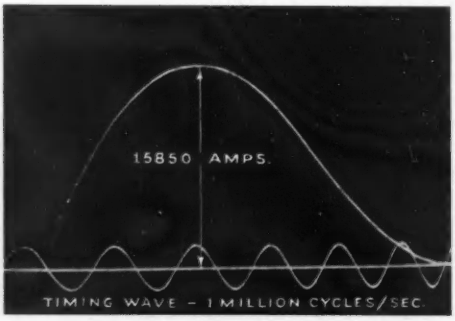



**Fig. 9.—Cathode-ray oscillograph record of the performance of a surge valve arrester, showing one of six heavy current surges, all of which were passed without trouble.**

its functions without serious damage. It has been found possible to secure the necessary strength and toughness without sacrificing any of the electrical attributes, and the 30 repeated surges specified at 1,500 amps. presented no difficulty. An established procedure is to follow this test with 6 further surges at about ten times the previous current, and the oscillogram in fig. 9 is a record of such a test at 15,850 amps.

The volt-ampere record, fig. 10, was taken by the cathode ray oscillograph during the last of the six discharges, which were made upon a commercial 22 kV arrester. To understand this curve, it should be borne in mind that a rapid wave-front followed by a slower tail has been generated, as in fig. 4, the crest voltage being reached in only 0·5 microsecond. The rising and falling portions have followed slightly different paths in fig. 10, the front being the less distinct owing to its more rapid movement, and requiring slightly more volts to pass the same current. If the return wave be compared with the 22 kV earthed neutral curve in fig. 8, it will be found that the correspondence is quite close, 65 kV producing about 1,200 amps. in each instance. The oscillogram shows that no harm has befallen the arrester in spite of the six discharges of over 15,000 amps. that have passed through it ; while a comparison with the similar curve taken before the heavy surges shows that an appreciable improvement has taken place in the valve action, owing to "ageing." Such an effect is usual when the discs are first put into service.

Another method of demonstrating the relief afforded is to take a klydonograph record of the circuit voltage before and after connecting in the arrester. A pair of klydonograms obtained under these conditions is shown in fig. 11, in which an 850 kV surge was applied to a 6·6 kV circuit equipped with a surge valve arrester having the appropriate rating. Both are positive figures and are reproduced strictly to the same scale.

The suppression of the follow-through power current is shown by the oscillogram in fig. 12, taken during the application of an 850 kV stroke to the arrester with a normal 6·6 kV power supply connected to it from a 1,000 kVA transformer. The current wave consists of a single loop, indicating that the follow-current was cut off at the first passage through zero. Every record of this description that has been taken has given the same result, *viz.*, in no case has the follow-current lasted more than one half-cycle.

## ARRESTER DETAILS.

The general arrangement of G.E.C. arresters will already have been gleaned from figs. 2 and 3, and the accompanying description. A list of the various ratings, with numerical particulars, is given in the table on page 12.

In this table, the discharge voltage consists of the line voltage multiplied by $2\frac{1}{4}$. The cut-off voltage is included because it is frequently asked for, but it is not of great importance, as the normal frequency follow-current is the quantity which requires sup-

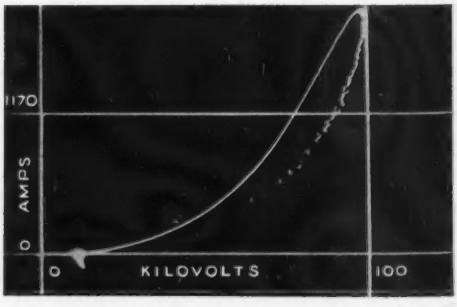


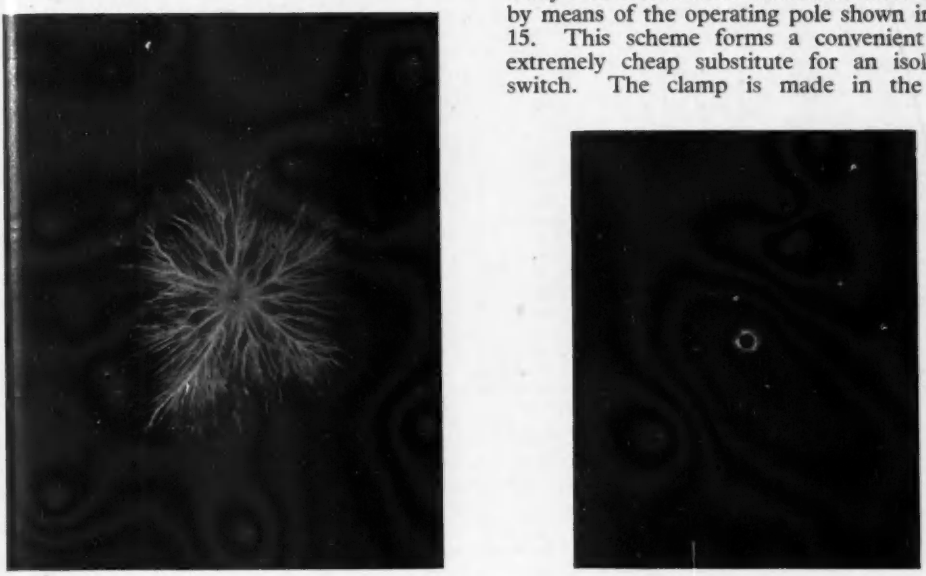

**Fig. 10.—Volt/ampere oscillogram, recorded after the heavy current surges of fig. 9.**

pression, and this is done at the first current zero as illustrated in fig. 12.

*Bracket Type.*

All the ratings of the bracket type are single units, consisting of the appropriate number of discs and gap-elements in a single porcelain enclosure of the correct size, the complete range being shown in fig. 13. They are supported by a clamping ring bracket as shown in fig. 14, fixed to a cross arm of a transmission pole or substation structure. Two typical methods of pole mounting are illustrated, of which (*a*) is an H-pole terminal support, and (*b*) one for a single wooden pole.

Connection is made from top-cap to line by means of "live-line" clamps, which can be easily connected and disconnected from below by means of the operating pole shown in fig. 15. This scheme forms a convenient and extremely cheap substitute for an isolating switch. The clamp is made in the two patterns shown in fig. 16, both of which are continuously rated for currents up to 150 amps. The vertical thrust type, shown in (*a*) embodies a ball-and-socket joint, which becomes perfectly rigid when the device is clamped to the overhead wire. The side engagement type is of simpler design, as shown in (*b*).



(a) (b)

**Fig. 11.—Klydonograph records of an 850 kV surge applied (a) before and (b) after inserting a surge valve arrester.**

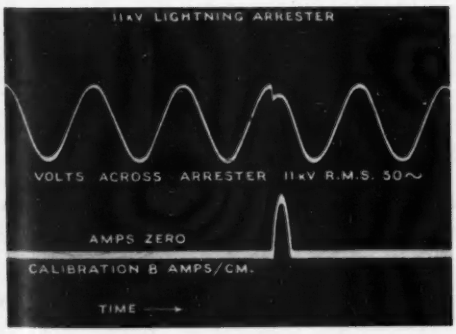



**Fig. 12.—Oscillograph record of the performance of a surge valve arrester, showing the limitation and interruption of the follow-through current.**

*Pedestal Type.*

Higher ratings are made up by connecting in series, both mechanically and electrically, the required number of 11 kV units, as illustrated in fig. 17. These are made with a flanged base cap to enable the necessary coupling to be effected, and to accommodate the pedestal fitting in the case of the lowest unit. All the models in the middle division of the table, namely those up to and including the 66 kV rating, are self-supporting when the base is rigidly fixed; but the higher rated group are mounted on ball-and-socket bases and have also ball-and-socket top-caps for coupling with supporting insulators. Ratings up to and including 44 kV can, however,

| Type | Maximum Line Voltage R.M.S. Value | | Approximate Operating Voltage | | Net Weight, lb. |
|---|---|---|---|---|---|
| | Three phase with neutral insulated or earthed through resistance | Three phase system with neutral solidly earthed | Discharge voltage, instantaneous value | Cut-off voltage, instantaneous crest value | |
| Bracket | 2,300 | 2,900 | 7,000 | 5,000 | 14½ |
| | 3,300 | 4,125 | 10,500 | 7,000 | 15¼ |
| | 5,500 | 6,600 | 16,800 | 12,000 | 23¾ |
| | 6,600 | 8,250 | 21,000 | 16,000 | 24 |
| | 8,800 | 11,000 | 27,000 | 20,000 | 31¾ |
| | 11,000 | 13,750 | 35,000 | 22,000 | 33 |
| | 17,600 | 22,000 | 56,000 | 40,000 | 64 |
| | 22,000 | 27,500 | 70,000 | 45,000 | 75 |
| Pedestal | 17,600 | 22,000 | 56,000 | 40,000 | 80 |
| | 22,000 | 27,500 | 70,000 | 45,000 | 93 |
| | 26,400 | 33,000 | 82,000 | 65,000 | 108 |
| | 33,000 | 41,250 | 105,000 | 75,000 | 121 |
| | 35,200 | 44,000 | 112,000 | 82,000 | 139 |
| | 44,000 | 55,000 | 140,000 | 92,000 | 151 |
| | 53,000 | 66,000 | 168,000 | 120,000 | 183 |
| | 66,000 | 82,500 | 210,000 | 140,000 | 215 |
| Pedestal | 62,400 | 77,000 | 195,000 | 140,000 | 292 |
| | 70,000 | 96,000 | 245,000 | 155,000 | 338 |
| | 70,000 | 88,000 | 224,000 | 160,000 | 325 |
| | 88,000 | 110,000 | 280,000 | 180,000 | 371 |
| | 105,000 | 132,000 | 336,000 | 216,000 | 437 |
| | 110,000 | 137,500 | 350,000 | 225,000 | 437 |
| | 132,000 | 165,000 | 420,000 | 270,000 | 503 |

be provided with special steel brackets to make them suitable for pole mounting.

*Thermal Disconnector.* Conditions sometimes occur in electric transmission networks causing persistent arcing to earth. These "arcing earths" give rise to voltage surges which the arrester would continuously relieve. If, however, such operation were permitted to go on indefinitely, the arrester would overheat and eventually be damaged. Bracket type arresters, which have a clear space below them, are fitted with a simple device for disconnecting them when a safe temperature is exceeded.

In these models the lower connection consists of a stud, to which the earth lead is taken through a flexible braid, shown in fig. 18. The stud is attached to the fixed earth terminal of the arrester by means of low-melting-point solder, melting at 70 degs. C.; and when this temperature is reached, the stud falls off and so breaks the earth circuit. The general arrangement is indicated in fig. 14.

*Grading Rings.* It is a well established fact that when a number of insulator links are connected between line and earth, the voltage gradient down the string is modified by the capacity of the links to earth. In consequence,

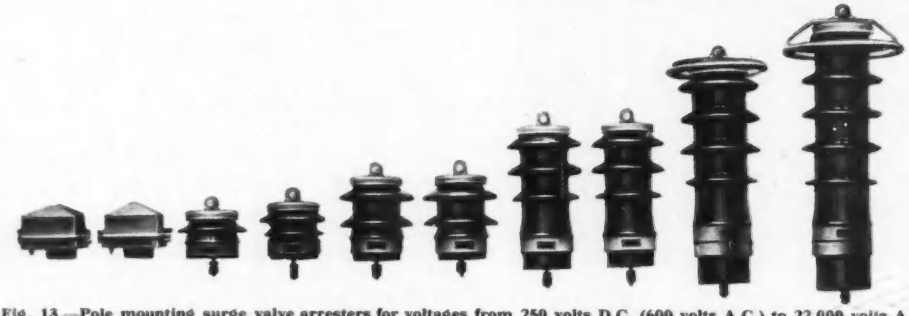


**Fig. 13.—Pole mounting surge valve arresters for voltages from 250 volts D.C. (600 volts A.C.) to 22,000 volts A.C. The overall height of the arrester at the right hand end of the illustration is 2ft. 3ins.**

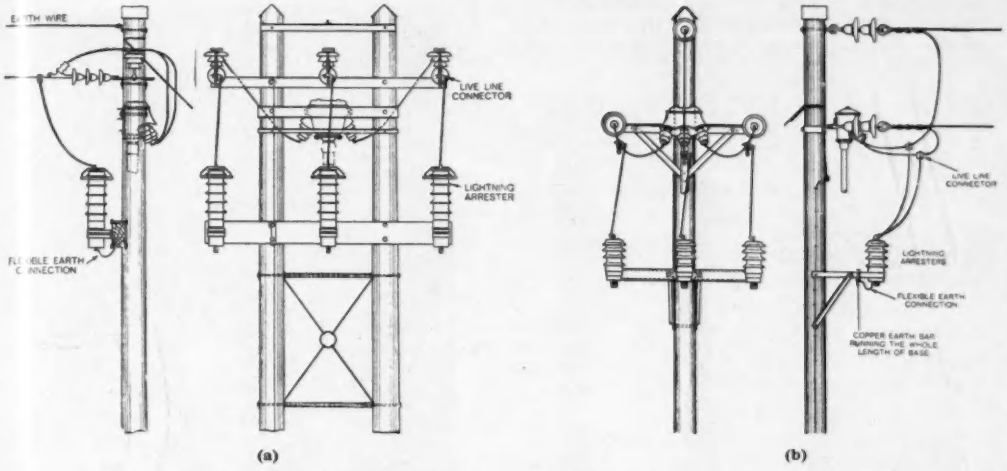



**Fig. 14.—Typical methods of mounting surge valve arresters showing live line clamps and flexible earth connections : (a) on an H type terminal pole, (b) on a single wooden terminal pole.**

sparkover will occur earlier than would otherwise be the case at the more highly stressed gaps, and the total sparkover voltage will be considerably reduced. Surge-valve arresters behave like a string of insulators, the effect becoming troublesome for arresters rated at 22 kV and above ; these models are accordingly fitted with grading rings at the upper end which act as a counterpoise neutralising the effect of the earth capacity at the lower end. The rings can be seen upon the arresters in fig. 17. A single ring is sufficient for the lower voltage ratings, its dimensions and position being finally settled by test ; but for the higher voltages, several rings are necessary, and the design becomes more critical. The final tests in the case of the 132 kV model, which is fitted with three rings, are shown in fig. 19.

### ADVANTAGES OF SURGE-VALVE LIGHTNING ARRESTERS.

The principal advantages of the surge-valve arrester over earlier types will already have been deduced from the foregoing description. First place must be given to the remarkable valve characteristic, upon which the success of the device is based. Second, the robust and permanent nature of every component renders maintenance unnecessary, and together with the compactness of the whole arrester makes an outdoor, and in many cases a pole-mounting, situation not only possible

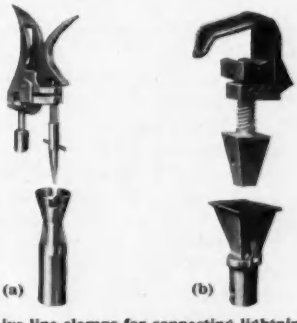



**Fig. 16.—Live line clamps for connecting lightning arresters to overhead line conductors : (a) vertical thrust type, (b) side engagement type.**

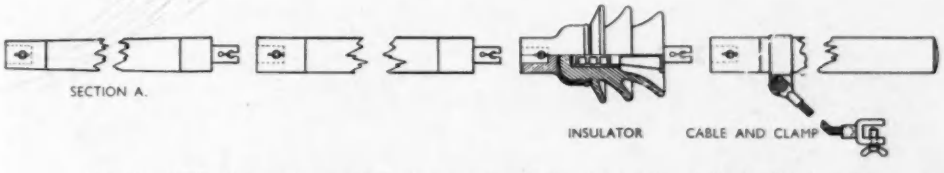



**Fig. 15.—Sectional type of operating pole. The top section A is made suitable for fixing to the head of the side engagement live line clamp shown in fig. 16 (b).**

but standard. There is no open arcing as with the horn type of arrester, and the extinction of the follow-current is effected smoothly,

**Fig. 17.—Pedestal mounting surge valve arresters, type M.G., for voltages of 22,000 and 66,000.**

**Fig. 19.—132 kV surge valve lightning arrester on test in the G.E.C. High Tension Testing Laboratory.**

without the voltage peaks that characterised the latter and some other apparatus. Its action is so instantaneous that the disturbance is relieved considerably before the peak voltage is reached. Deterioration is almost nil, the characteristics of the valve discs actually improving with age. Finally the cost is much lower than that of the more important preceding types.

## CONCLUSION.

There is no doubt that the lightning arrester is taking its place among the precision devices for safeguarding electrical equipment. The type of surge-valve arrester described in this article has been shown both by stringent tests and by its performance in the field to afford a most valuable safeguard against the effects of lightning and other voltage surges; while the newly-designed testing and recording apparatus, coupled with the far-reaching results of recent researches, give every promise of continuously improving results in the near future.

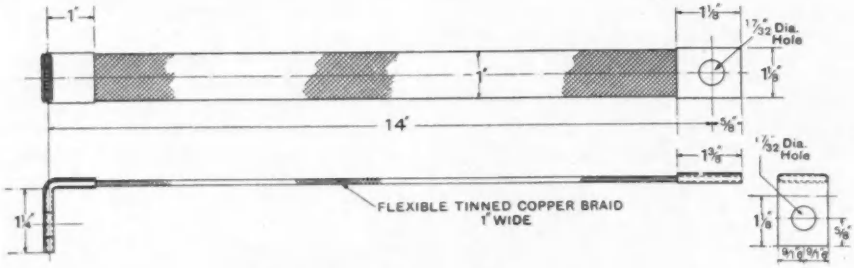



**Fig. 18.—Flexible copper braid for type M.G. arresters.**

# Television Film Transmitters using Apertured Scanning Discs.

## PART II.

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### (5) TRANSMITTER ASSEMBLY (I.M. SYSTEM).

#### (5.1) Mechanical Features.

In order to give the maximum flexibility in early experimental work the complete scanner assembly shown in fig. 29 was designed as a massive optical bench. The whole of the film traction equipment is mounted as a hinged member so that the cover of the scanning-disc chamber of fig. 30 can be removed. This member is normally bolted rigidly to the main I.M. optical system and disc chamber mounting, so that relative movements are reduced to a minimum.

Some work on trapezoidal projection has been done on the apparatus, and to facilitate this the film gate and scanning-disc chamber were arranged for rotation about axes passing through the optical axis. These adjustments are no longer required for the I.M. system.

Many forms of picture distortion can arise from errors in the mechanical assembly of a scanner. The only point of the gate image which remains stationary throughout two frame periods lies on the optical axis, and this point must be scanned by the mean hole (203). Vertical adjustments are provided so that this condition can be satisfied. Horizontal mis-alignment has only a second-order effect.

The whole of the synchronizing optical system is mounted directly on the scanning-disc chamber, and a screw height adjustment on the source side provides a control of line impulse phase.

#### (5.2) Power Equipment and Control Circuits.

The transmitter equipment requires two main supplies of 415 volts, 3-phase, 50 c./s., and 3-wire (120 + 120) volts (D.C.). The A.C. supply feeds all the synchronous machinery and the rack equipment. Direct current is required for the light source and all starting and control circuits. The complete arrangement is shown in fig. 31.

The motors driving the various mechanical components of the transmitter are of the synchronous induction type designed to be as free as possible from phase wander. By using these it is possible to ensure that the rotating members of the machine run at exact speed and in the correct phase relationship, although not coupled mechanically.

The control circuits for these machines are all push-button operated by means of light-duty D.C. contactors which, for reasons dealt with later, are electrically interlocked for protection and to ensure the correct sequence of starting.

#### (5.2.1) Synchronous Drives.

The disc driving motor, enclosed in the disc vacuum chamber, has to meet somewhat unusual conditions of running. Due to the fact that it is operating in air at low pressure, the cooling of both rotor and stator can only be by conduction. Heat transfer takes place from the rotor along the shaft and through the bearings, and for this reason the bearings are cooled by water jackets. The stator is in contact with the outside wall and with the water jackets. Another feature of the motor demanded by the low air pressure ( < 3 mm. of mercury) is that the maximum line voltage must not be more than the striking potential at such a pressure in order to avoid an electrical discharge taking place between the motor terminals or adjacent high-potential sections of the windings. The motor is wound for a line voltage of 80 volts. The input of the motor when running synchronously, and in the correct working pressure, is about 0·42 kVA. In view of the fact that the disc motor runs at 6,000 r.p.m. the frequency of the supply must be 100 c./s. This power is obtained from a small motor-alternator set provided with a flywheel. Since a synchronous induction motor of the type used has a

tendency to snatch into synchronism after being run up as a normal induction motor, there is the possibility of introducing damaging torques at the centre of the thin disc structure. To avoid this trouble the disc motor is permanently electrically coupled to the motor alternator, and the latter is gradually run up to speed by motoring the alternator exciter from the D.C. mains. When running at the correct speed, and when the correct phase relationship of the disc motor and the 50-cycle mains is established by means of a gas discharge synchroscope, the motor of the alternator set is connected to the main 50-cycle supply and the D.C. mains are removed from the exciter, which then performs its normal function. By adopting this method no shock is imparted to the disc during the synchronizing process. The electrical coupling between the alternator and the disc motor is extremely rigid ; in fact if the alternator is rotated slowly by hand the disc motor will follow, and this allows any hole of the disc to be inspected through one of the windows without opening the disc chamber.

Intermittent-magnification and interceptor motors are operated at 1,500 r.p.m. and 750 r.p.m. respectively, and are of the same type as the disc motor except that they are connected to the 50-cycle mains and are self-ventilated. They are switched directly on to the mains via push-button-operated contactors.

The I.M. motor running at 1,500 r.p.m. can start up and run in either phase position with respect to the scanning disc. The interceptor motor must be switched in phase to co-operate with the correct disc spiral. The rotors of all motors are adjusted in position during initial scanner trials so that exact phases are always available subsequently by simple switching.

The film traction equipment is driven by a 3,000 r.p.m. motor of considerable inertia. The starting characteristics of this motor are adjusted so that violent acceleration and possible damage of the film are avoided.

**(5.2.2) Control and Operation.**

All the control gear for the motors and the motor-alternator set are grouped together on

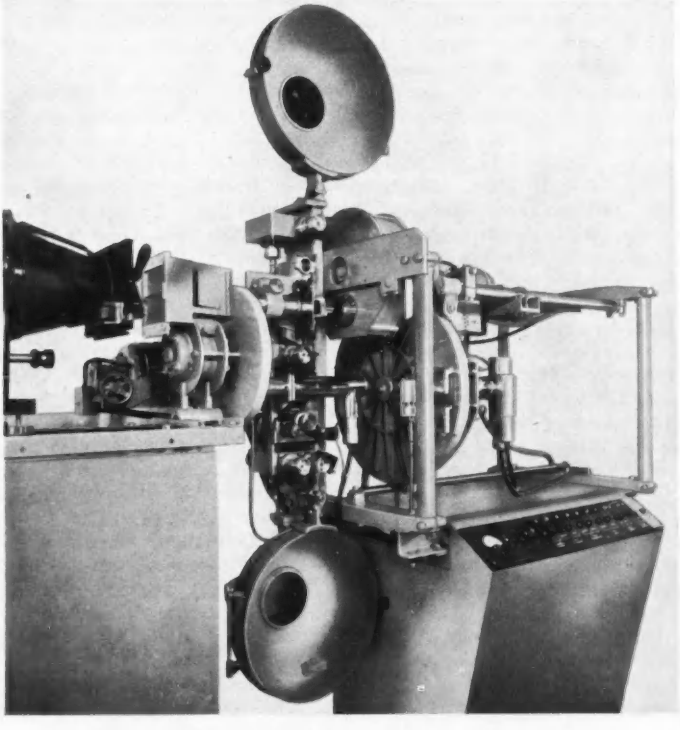


**Fig. 29.—Complete I.M. scanner assembly.**

one panel. Remote control of this panel is obtained by the use of light-duty D.C.-operated contactors which are connected to "start" and "stop" push-buttons grouped together on the scanner assembly. The contactors are electrically interlocked for reasons mainly concerned with the scanning disc and its drive. The

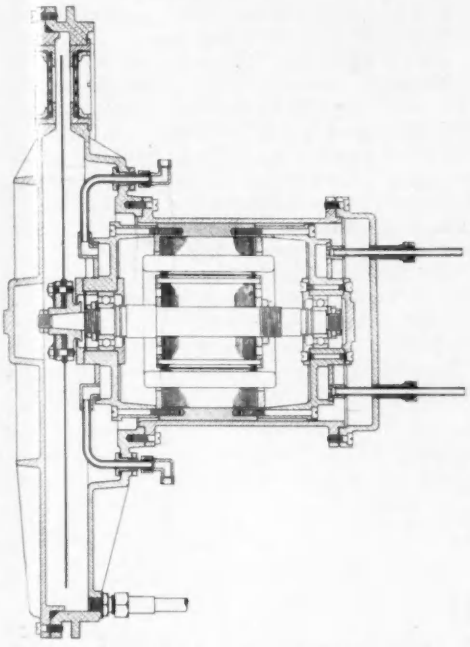


Fig. 30.—Scanning disc vacuum chamber assembly.

disc must not be run up to speed unless the air pressure is below a definite value, and cooling water must be flowing in the bearing jackets (see fig. 30). A manometer switch and a flow-controlled water switch are connected in series, and only connect the control circuit supply when proper disc running conditions have been established.

To avoid damage to the scanning disc the arc light cannot be run until the interceptor disc is running at synchronous speed. No interlock is required for the film drive as, with the interceptor disc running, the gate and film temperatures do not rise to dangerous values.

To avoid trouble arising from temporary failure of the A.C. mains, which would leave the equipment in the "on" condition, a no-volt release is fitted to the A.C. supply to bring out the D.C. contactor circuits. The operation of the interlock features can be seen from the detached contact schematic of fig. 31.

When starting the motor-alternator, and hence the tightly-coupled disc motor, the D.C. exciter contactor A is closed, and the machine run up on direct current. During this period operation of the A.C. motor contactor B is prevented, and continues so until preparer contacts $S_1$ are closed by the D.C. starter rheostat S reaching its maximum position. The machine must then be synchronized to the 50-cycle mains and the synchronizing button operated. This immediately closes the A.C. motor contactor B. Contact $B_1$ short-circuits contactor A control coil, and A drops out. The motor-alternator set is now running locked to the mains and the exciter is connected to the alternator.

### (6) VISION CHANNEL EQUIPMENT.

#### (6.1) Vision Amplifier.

The main vision amplifier is shown in fig. 32. Each stage is specially equalized at low frequencies by a method, published by Edwards and Cherry,* in which the cathode, anode and screen circuits ($R_4C_4$, $R_5C_5$ and $R_6C_6$ respectively) are so proportioned that the stage acts as a perfect D.C. amplifier over the low-frequency range. Two long-time-constant, but non-conductive, coupling circuits are associated with the first two anode circuits of $V_1$ and $V_2$, but the datum (black level) of the signal is restored by a diode $V_3$ according to well-known practice. Such D.C. reinsertion is accurate enough if the diode is of very low impedance, so that condenser $C_9$ can be charged to the full extent from the source, of impedance $R_8R_9/(R_8 + R_9)$, in a time of the order of the black period. The circuit is designed to assist this operation as the signal from $V_2$ is about 20 volts, and is much larger than is necessary to drive the grid of $V_4$. In this way the difficulties of D.C. reinsertion, depending on diode current at low levels, are very much reduced. The necessary voltage step-down is obtained by a distortionless potentiometer comprising $R_{10}$, $C_{10}$, $R_{11}$, and the input capacitance $C_{g4}$ of $V_4$ so arranged that $R_{10}C_{10} = R_{11}C_{g4}$.

The output stages are conductively coupled[25] to ensure that the two grids are driven by substantially equal and opposite voltages at all frequencies within the signal range. The balance can be adjusted by potentiometer $R_{12}$ so that no signal current flows in the supply circuit. This balanced connection materially

* G. W. Edwards and E. C. Cherry: "Amplifier Characteristics at Low Frequencies, with particular reference to a New Method of Frequency Compensation of Single Stages," *Journal I.E.E.*, 1940, 87, p. 178.

improves the amplifier stability and eases the power supply problem. Positive and negative picture signals are available from $V_4$ and $V_5$ respectively.

The power equipment is provided with a choke input type of smoothing circuit to reduce the backward impedance which could act as a common coupling impedance in all stages. The smoothing circuit is terminated in an anti-flutter stage to remove all mains fluctuations from the H.T. line. A high-slope triode $V_6$, with a long-time-constant $R_{14}C_{14}$ grid circuit, acts as a distortionless unity gain amplifier at all fluctuation frequencies which could be transmitted effectively through the amplifier. Exact balance is obtained by adjustment of potentiometer $R_{14}$.

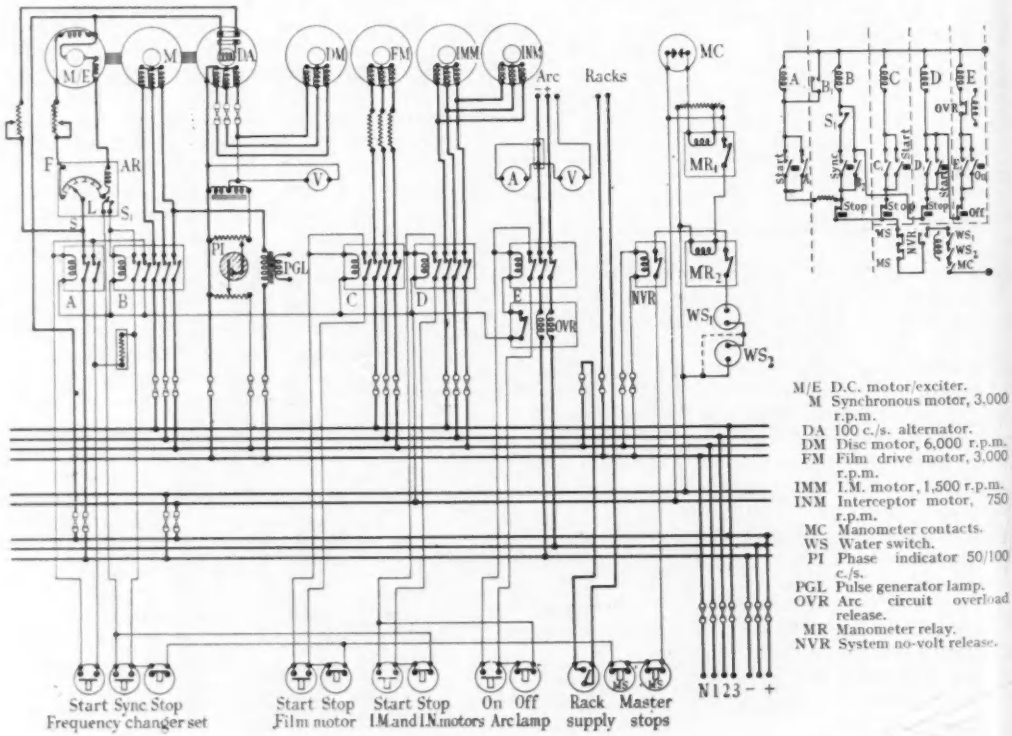
The corrections of the high frequency transmission characteristics of the amplifier are described in Section 11·2 and the resultant values of gain variation and phase delay $\beta/\omega$ are shown in fig. 33. It will be seen that the amplifier is given a slight rise of gain of 0·8 db. at the top frequencies, and this is one contribution to the reduction of the disc aperture distortion factor $k$ which, at any frequency $f$, is of the approximate form :—

$$k = \frac{N^2 a\rho}{\pi f} \sin\left(\frac{\pi f}{N^2 a p}\right) \quad \cdot \quad \cdot \quad (44)$$

Phase irregularities are not introduced by the finite aperture effect as the hole is symmetrical about a transverse diameter, so that the signal distribution would be unmodified by reversal of the scanning motion.

Amplifier phase distortion is often expressed in terms of the phase delay $\beta/\omega$, and this varies by only 0·025 microsec. up to 3·0 Mc./s., at which point the gain begins to drop too fast for undesirable transient effects to occur. Over most of the frequency range the phase delay is constant at 0·23 microsec. The variation of the group delay $\delta\beta/\delta\omega$ over the same range is 0·073 microsec.

By the use of a low-pass filter connection the effective load resistance of the input circuit is as high as 3,000 ohms for a distributed capacitance of about 30μμF. The load impedances of the various stages are dissimilar owing to the need for equalization




M/E D.C. motor/exciter.
M Synchronous motor, 3,000 r.p.m.
DA 100 c./s. alternator.
DM Disc motor, 6,000 r.p.m.
FM Film drive motor, 3,000 r.p.m.
IMM I.M. motor, 1,500 r.p.m.
INM Interceptor motor, 750 r.p.m.
MC Manometer contacts.
WS Water switch.
PI Phase indicator 50/100 c./s.
PGL Pulse generator lamp.
OVR Arc circuit overload release.
MR Manometer relay.
NVR System no-volt release.

**Fig. 31.—Interlocked power supply circuit.**

and phase compensation. Resistances $R_3$ and $R_8$ $R_9/(R_8 + R_9)$ are 2,000 ohms and 3,600 ohms respectively so that, by using K.T.Z.41 valves ($V_1$ and $V_2$) at 7·5 mA/volt, a gain

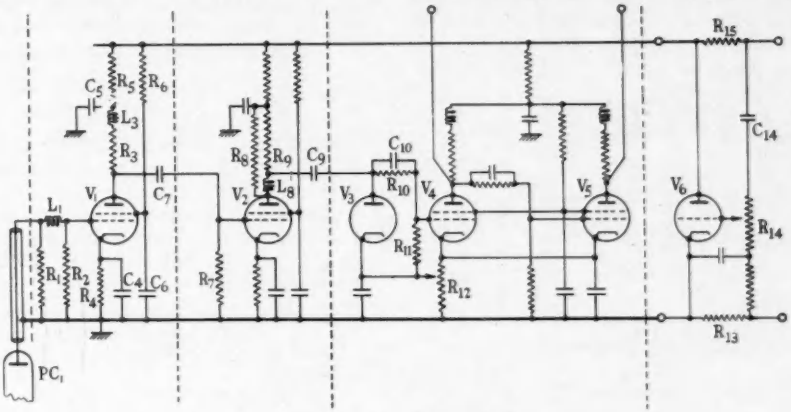



Fig. 32.—Main vision amplifier.

to $V_3$ of about 400 is available. Gain control is effected by variation of the photocell conditions as, with the type of circuit indicated, a change of valve parameters would influence the low-frequency characteristic of the amplifier.

**(6.2) Signal/Noise Ratio.**

The light which passes through the disc is concentrated on the cathode plate of an electron multiplier photocell. The white level flux has been assessed as 0·0042 lumen, and as the primary cathode sensitivity is 20 μA/lumen a primary current of 0·084 μA is available. This corresponds to about $10^5$ electrons per picture point.

If the primary current is $GL$, in which $G$ is the primary sensitivity in amperes per lumen, then it is known that the R.M.S. noise current over the frequency range $f$ cycles per sec. is :—

$$I_n = 5{\cdot}65 \times 10^{-10} \times [GLf]^{\frac{1}{2}} \text{ amp.} \quad \cdot \quad (45)$$

The ratio of white signal current $I_m$ to noise current $I_n$ is thus

$$\frac{I_m}{I_n} = 1{\cdot}77 \times 10^9 \times \left[\frac{GL}{f}\right]^{\frac{1}{2}} \quad \cdot \quad (46)$$

If the range of $f$ is taken up to the picture point frequency $\frac{1}{2}(N^2ap)$ then, from equation (24),

$$\frac{I_m}{I_n} = 1{\cdot}39 \times 10^{10} \times \left[\frac{BGr^2q^2\eta}{N^6a^3K^2m^2p}\right]^{\frac{1}{2}} \cdot \quad (47)$$

It is usually necessary to provide some secondary emission magnification of the primary current in order to obtain a maximum signal/noise ratio[26] substantially unmodified by the amplifier input noise.

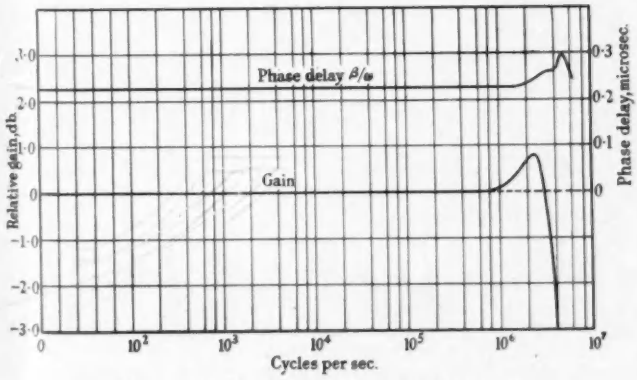



Fig. 33.—Transmission characteristics of vision amplifier.

Using the scanner parameters given in this paper the signal/noise ratio $I_m/I_n = 257$ over the frequency range to 3·0 Mc./s. The amplifier gain up to the D.C. reinsertion stage (20 volts peak signal) is 400, and so the corresponding input signal is 50 mV. This signal is obtained by using a secondary emission magnification of 210. The component of primary noise at the input of the amplifier is 195μV. The thermal agitation $V_{n1}$ and shot noise $V_{n2}$ levels at the same point are obtained from :—

$$V_{n1} = 1{\cdot}26 \times 10^{-10} \times [Rf]^{\frac{1}{2}} \text{ volts (R.M.S.)} \quad (48)$$

$$V_{n2} = 3{\cdot}1 \times 10^{-10} \times \left[\frac{I_a f}{g^2}\right]^{\frac{1}{2}} \text{ volts (R.M.S.)} \quad (49)$$

in which it is assumed that the first valve is a pentode of grid-anode conductance $g$ and an anode current $I_a$. Voltages $V_{n1}$ and $V_{n2}$ are 12μV and 6·5μV respectively, and it will be seen that the total contribution of these components is 13·6μV, which is well below the noise level (195 μV) of the photocell output. In fact the secondary emission gain could be reduced to 10 before the amplifier noise became significant. The use of a higher gain is simply concerned with convenience, and not fundamental difficulty, of amplifier construction.

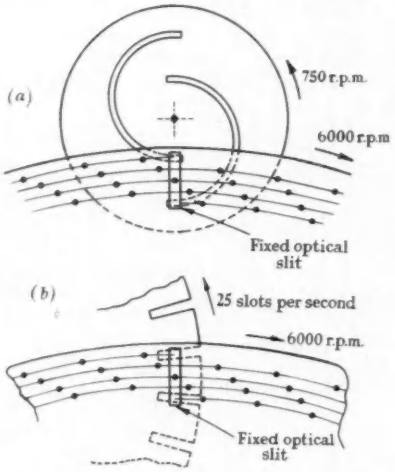



**Fig. 34.—Arrangements employed when using synchronizing hole spiral.**

The photocell has a plate type cathode, and it is known that a cathode on a glass wall can be made with a sensitivity of about 50 μA/lumen, so that an improvement of signal/noise ratio up to about 400 is to be expected.

It should be noted that the inherent primary noise vanishes when the signal vanishes, so that there is no granulation in dark parts of the picture. Thus this primary noise differs from amplifier input noise which persists throughout any modulation range of the vision signal.

The only other possible source of persistent noise arises from the thermionic emission of the caesium cathode. Fortunately this current is only about $10^{-5}$ μA/cm² at 20 degs. C. and can be neglected in most equipment.

By substituting in equation (45) the value of $L$ from equation (24), and putting $f = \frac{1}{2}(N^2ap)$, it can be seen that :—

$$I_n = 22{\cdot}2 \times 10^{-10} \times \left[\frac{BGr^2q^2p\eta}{N^2aK^2m^2}\right]^{\frac{1}{2}} \quad (50)$$

The disc peripheral velocity is proportional to $rq$, for a given picture repetition, and the disc stresses have been shown to vary as $r^2q^2\rho$. The scanning resolution, or number of picture points, is proportional to $N^2$, and so it can be stated that the noise level is constant if the disc stresses are increased as the required resolution is increased. On this basis the limit of resolution is set by the strength/density ratio of the disc material.

### (7) SYNCHRONIZING SIGNALS.

The wave form of synchronizing signals must be at least as accurate in time as the picture information with which it is associated. Mechanical scanners have the great advantage that no separate impulse generator is necessary, as the scanning member itself can be adapted to originate the required signals. In fact a separate generator can give rise to irregularities between the picture and synchronizing signals. The high inertia of a disc and its driving equipment is part of a very efficient electro-mechanical filter between the supply mains and the signal outlets. In this way not only is there a fixed relationship between the picture and synchronizing impulses, but the combined wave form is

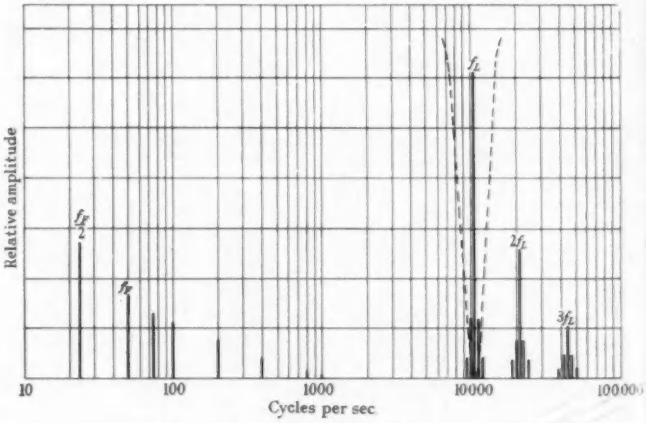



**Fig. 35.—Energy spectrum of synchronizing impulses.**

periodic in absolute sense. The first condition would be sufficient for receivers using electronic scanning controlled by an instantaneous trigger action, but the use of mechanical receivers in which considerable flywheel effect is present demands the second condition.

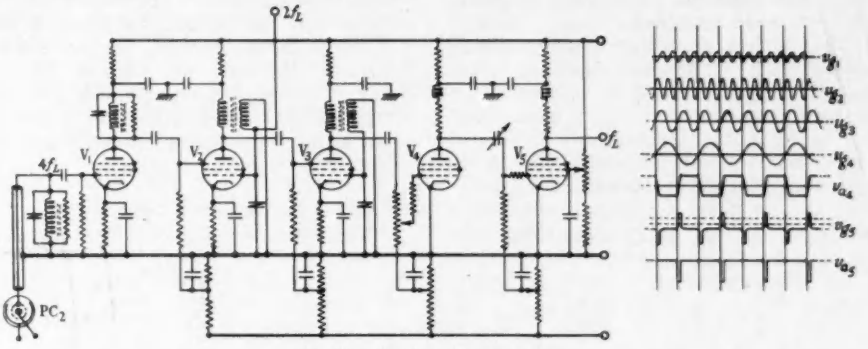



Fig. 36.—Line impulse generator.

A method has been proposed in which the scanning holes themselves control the light to a photocell at the input of the impulse circuits, but in the present case a separate arrangement of large apertures in the disc is used in order to avoid noise-level and amplifier difficulties. These apertures allow pulses of light, from an optical slit, to reach the photocell.

The original apparatus of fig. 34 used 405 apertures on four turns of a spiral[27] just below the scanning field, and an image of a narrow sector of the spiral was formed on a 750-r.p.m. double-slot interceptor so that each aperture operated once per four revolutions of the disc (*i.e.* in 1/25 second). The energy spectrum of the resultant wave form of the photocell current is interesting and is shown roughly in fig. 35. This could be represented by a two-dimensional Fourier analysis.[28] It is theoretically possible by suitable shaping of apertures and slit to produce only the line frequency $f_L$, but in practice harmonics of $f_L$ appear. The very small irregularities of aperture size and position which occur over the total length of the spiral introduce a fundamental component at picture frequency $f_{F/2}$ and its harmonics, but the troublesome effect appears as a modulation at these frequencies of the components $f_L$, $2f_L$, $3f_L$, etc. In some early experiments the low-frequency components were emphasized by introducing a deliberate irregularity of hole size and spacing over small lengths of the spiral (*e.g.*, by omitting two groups each of about 15 consecutive holes) and separating the frequency $f_F$ by a selective amplifier, so that frame and line impulses were available from one photocell outlet. The consequent disturbance of line impulses by frame-frequency modulation was prohibitive, and the method was abandoned.

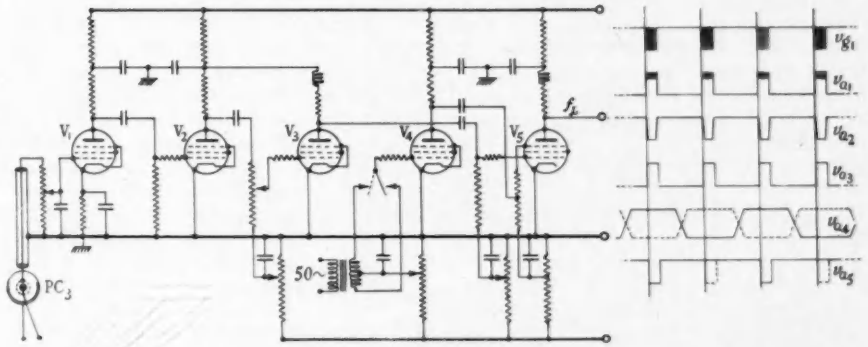



Fig. 37.—Frame impulse generator.

**(7.1) Line Impulse Generator.**

The line impulse generator must be controlled by component $f_L$, and in order to remove the modulation irregularities the photocell was followed by several highly selective stages of amplification with efficient amplitude-limiting properties. For reasons of phase stability of the line impulses it was decided, in the final apparatus, to reduce the time delay in the amplifier. This could only be done by increasing the band width, and in order to avoid a consequent increase of amplitude of the nearest side frequencies, displaced by only 25 c./s. from $f_L$, it was considered preferable to modify the synchronizing hole

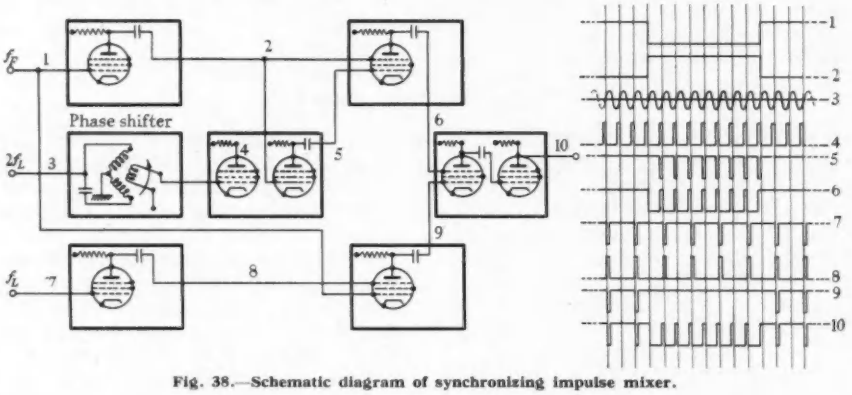



**Fig. 38.—Schematic diagram of synchronizing impulse mixer.**

spiral so that the photocell current was repeated every revolution of the disc. The lowest modulation frequency is then 100 c./s.

If all disc holes pass through the effective optical system during one revolution it is clear that the number per four revolutions cannot be 405. It is satisfactory to provide 405 holes in a circle and divide the frequency of the output component $4f_L$ by four in a special circuit. In the latest disc shown in fig. 28 the holes are disposed in three circles[29] of 135 holes each, to avoid disc buckling and reduction of strength which could arise when the spacing is very little more than the hole diameter. Promising methods of frequency division by mechanical means are under development, and typical forms are described in sub-section (11.3).

The line impulse circuit of fig. 36 is controlled by a sinusoidal voltage, of frequency $4f_L$, from a second C.W.S.24 photocell. Two threshold oscillators in cascade each divide the control frequency by two, so that the sinusoidal components $2f_L$ and $f_L$ are separately available. The latter drives impulse-shaping stages $V_4$ and $V_5$ in the diagram. Owing to the need for rather critical control of threshold oscillators it is likely that future equipment will use multivibrator stages for frequency division. The length of the final impulse is determined by the time-constant of the grid circuit of $V_5$, and by the working point of the valve as adjusted by the bias potentiometer. The frequency characteristics of all subsequent valves conveying the line impulse are corrected so that the wave form is as steep as possible.

**(7.2) Frame Impulse Generator.**

The frame impulses are produced by the circuit of fig. 37. Two short groups of light pulses reach the C.W.S.24 photocell per frame period, and the coupling circuits are so arranged that the serrations in the wave form are eliminated by long-time-constant networks, in combination with sharp amplitude-limiting in the valves. A control voltage of approximately square wave form, and period 0·02 sec., is produced by valve $V_4$ which is overdriven from the mains. This voltage is arranged to suppress one of the two frame impulses so that at the output of $V_5$ the required frame frequency impulse is available for control of the synchronizing impulse mixer shown in fig. 38.

**(7.3) Synchronizing Impulse Mixer.**

The synchronizing impulse mixer[30] shown diagrammatically in fig. 38 is controlled by the impulses at $f_F$ and $f_L$ and by a sinusoidal component of $2f_L$. The circuit is cross-connected so that line impulses cannot appear during the frame impulse. Double-line-frequency impulses are produced only during the frame impulse, and these are used to

suppress the frame impulses as shown in the wave-form diagram. Output stages are provided for the combining of line and modified frame impulses, and the output is available either for mixing with the picture signal or for separate modulation of the radio transmitter.

All impulse circuits are connected to voltage-stabilized power supplies so that the time position of all impulse boundaries is unaltered by mains fluctuation.

### (8) RADIO EQUIPMENT.

The installation is arranged to provide 10 watts of radio output ($\lambda \simeq 7$m.) at a modulation level corresponding to the white signal. The unmodulated sound carrier output is usually set at about 3 watts. Feeders from the transmitter can be connected either to aerial arrays or to a network of co-axial feeders for receiver testing in various distant locations. The second rack in fig. 39 contains the frequency-doubler stages for both channels. A crystal-controlled oscillator is used in the sound channel in order to provide signals stable enough in frequency for the testing of television receivers with narrow-band sound circuits.

The ratio of black to white carrier levels is adjustable by a symmetrical bias control on the grids of push-pull pentodes in the vision output stage. At present the modulation is applied directly to this stage. Early experiments with a low-level modulator were unsatisfactory, as all subsequent amplification had to be obtained with wide-band circuits if a large output was required. The modulator was interesting as it took the form of a pentode stage overdriven at half frequency on the control grid, and with picture-frequency modulation applied to the suppressor grid. Modulation and frequency-doubling took place simultaneously and, as the output circuit was tuned to twice the drive frequency, very good suppression during the synchronizing impulse periods could be obtained.

In order to increase the usefulness of the installation for test purposes, modifications are in hand for the provision of low-level modulators giving small outputs at carrier frequencies to fit the intermediate-frequency bands of superheterodyne vision receivers.

### (9) ACKNOWLEDGMENT.

The final projection lens for the I.M. system was designed and made by Messrs. Taylor, Taylor and Hobson, Ltd., and the authors wish to thank Mr. A. Warmisham of that company for valued assistance.

### (11) APPENDICES.

#### (11.1) The Tunnel Effect.

When an image is formed in the plane of a disc it is clear that some light which enters the scanning hole will be lost at the cylindrical surface of the hole unless the disc windows are of zero thickness or the associated optical system has an infinitesimal aperture. The condition is shown in fig. 40 and it is assumed that the disc plane is illuminated by the flashed exit pupil, of the main optical system, of brightness $B$ and cone half-angle $\beta$. The

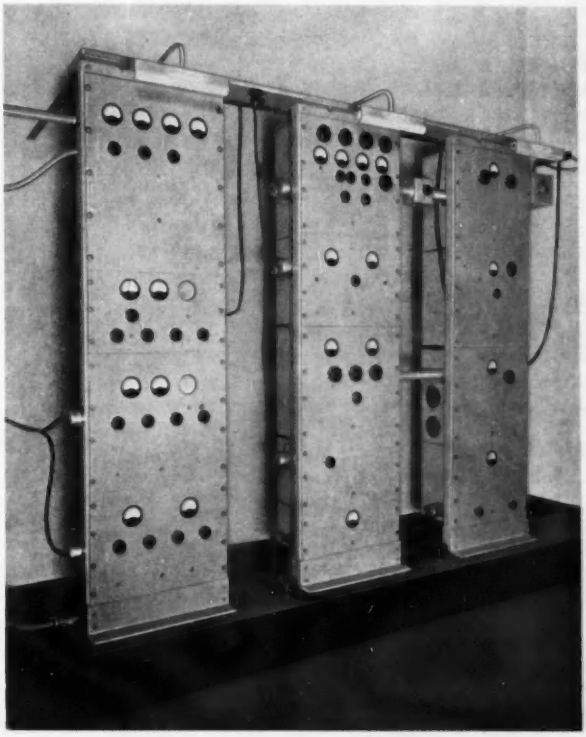


Fig. 39.—Signal control and radio equipment.

limiting case is given when $\beta = \frac{1}{2}\pi$, which is equivalent to a system in which the entrance pupil of the hole is covered by a luminous plane of brightness $B$.

There is then some angle, given by $\theta_{max} = \arctan(d/t)$, beyond which no light

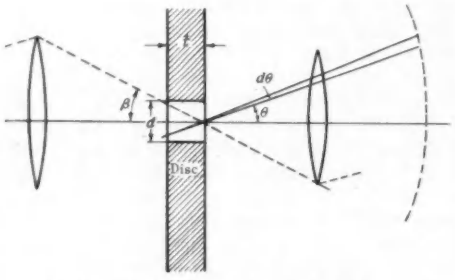



**Fig. 40.—The geometry of the tunnel effect.**

can pass through the hole. The total transmitted light flux is :

$$\frac{\pi d^2 B}{4}\int_0^{\arctan\left(\frac{1}{k}\right)} 2\sin 2\theta\,[\arccos(k\tan\theta) - k\tan\theta\,(1-k^2\tan^2\theta)^{\frac{1}{2}}]d\theta \quad (51)$$

in which $k = t/d$.

The absolute maximum flux is obtained when $t = 0$, and $\theta_{max} = \frac{1}{2}\pi$, and has a value $\pi^2 d^2 B/4$. The transmission factor is thus

$$\frac{1}{\pi}\int_0^{\arctan\left(\frac{1}{k}\right)} f(\theta)d\theta \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (52)$$

and is shown in one of the sets of curves of fig. 41. Actually $\beta$ can never be as great as $\frac{1}{2}\pi$, and before performing the integration it is necessary to determine the relative magnitudes of $\beta$ and $\theta_{max}$. The limits of the definite integral must be the smaller of $\beta$ and $\theta_{max}$. Further curves of $f(\theta)$ are shown in fig. 41 for a few typical values of $k$, and the condition for the integral limits has been imposed in all cases. It is entirely useless to employ a lens stop giving $\beta$ greater than $\theta_{max}$, as all extra light is lost. A small amount of light is reflected from the sides of the hole, but most of this is lost by scattering.

From the point of view of efficiency the disc window should be made as thin as possible, but when $d$ is only about $37\mu$ the thickness has a lower limit set by mechanical stability considerations. A maximum limit is set as $t/d$ should not exceed about unity if good hole-punching conditions are to be maintained. There is some compensation for the light loss of thick windows, as it can be shown that a window of finite thickness is equivalent to a zero-thickness window covered by an absorbing film across the hole. In effect this film gradually increases in density towards the edges and hence the hole is apparently smaller in size, giving a scanning definition better than would otherwise be expected.

**(11.2) The Transmission Characteristics at High Frequencies of Picture Frequency Amplifiers.**

Various forms of coupling circuits for reducing the deleterious effects of stray capacitance are shown in fig. 42. It is convenient to assess the gain characteristic as a variation in decibels ($\alpha$) from the datum gain at very low frequencies, in which case the load impedance is $R_A$, $R_B$ or $R_C$ for the three examples given. Assignable circuit parameters are :—

$$k_A = \frac{L_A}{CR_A^2}; \quad \Omega_A = R_A C\omega$$

$$k_B = \frac{L_B}{CR_B^2}; \quad \Omega_B = R_B C\omega$$

$$k_C = \frac{L_C}{CR_C^2}; \quad \Omega_C = R_C C\omega$$

*Type A circuit.*

$$\alpha = 10\log_{10}\left[\frac{1+k_A^2\Omega_A^2}{(1-k_A\Omega_A^2)^2+\Omega_A^2}\right]\text{db.} \quad (53)$$

The phase shift

$$\beta = \arctan\left[k_A\Omega_A - k_A^2\Omega_A^3 - \Omega_A\right] \quad (54)$$

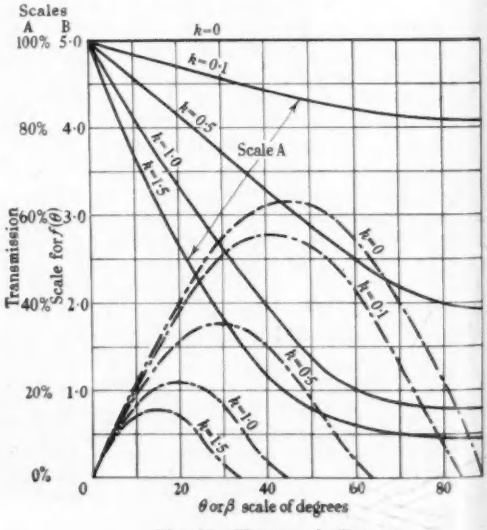



**Fig. 41.—The tunnel effect.**

The phase delay

$$\frac{\beta}{\omega} = \frac{\beta}{\Omega_A} . R_A C \text{ sec.} \quad . \quad . \quad . \quad . \quad (55)$$

The group delay

$$\frac{d\beta}{d\omega} = \frac{R_A C[k_A(1-3k_A\Omega_A^2)-1]}{1+\Omega_A^2[k_A(1-k_A\Omega_A^2)-1]^2} \text{ sec.} \quad (56)$$

*Type B circuit.*

$$\alpha = 10 \log_{10}\left[\left(1 - \frac{k_B\Omega_B^2}{2}\right)^2 + \frac{\Omega_B^2}{16}(4 + k_B - k_B\Omega_B^2)^2\right] \text{db.} \quad . \quad . \quad (57)$$

$$\beta = \text{arc tan}\left[\frac{\Omega_B(4 + k_B - k_B\Omega_B^2)}{(2 - k_B\Omega_B^2)}\right] \quad . \quad (58)$$

$$\frac{d\beta}{d\omega} = \frac{R_B C}{8}\left[\frac{8 + 2k_B - 2k_B\Omega_B^2 + k_B^2\Omega_B^2 + k_B^2\Omega_B^4}{\left(1 - \frac{k_B\Omega_B^2}{2}\right)^2 + \frac{\Omega_B^2}{16}(4 + k_B - k_B\Omega_B^2)^2}\right] \text{ sec.} \quad . \quad (59)$$

The gain of this circuit never rises above the datum gain but is equal to it at a frequency given by $\Omega_B^2 = (4 - k_B)/k_B$.

*Type C circuit.*

$$\alpha = 10 \log_{10}\left[\left(1 - \frac{k_C\Omega_C^2}{2}\right)^2 + \frac{\Omega_C^2}{16}(4 - k_C\Omega_C^2)^2\right] \text{db.} \quad (60)$$

$$\beta = \text{arc tan}\left[\frac{\Omega_C(4 - k_C\Omega_C^2)}{4 - 2k_C\Omega_C^2}\right] \quad . \quad . \quad . \quad (61)$$

$$\frac{d\beta}{d\omega} = \frac{R_C C}{8}\left[\frac{8 - 2k_C\Omega_C^2 + k_C^2\Omega_C^4}{\left(1 - \frac{k_C\Omega_C^2}{2}\right)^2 + \frac{\Omega_C^2}{16}(4 - k_C\Omega_C^2)^2}\right] \text{sec.} \quad (62)$$

In the amplifier of fig. 32, the characteristics of which are shown in fig. 33, two A type circuits and two B type circuits are used with parameters given approximately by $k_A = 0{\cdot}85$, $k_B = 0{\cdot}6$ and $\Omega_B/\Omega_A = 1{\cdot}51$.

Most calculations of multi-stage circuits are greatly facilitated by the use of families of curves in terms of the parameters $k$ and $\Omega$ for the various coupling arrangements. This work has been found to be very valuable and much time is saved in the synthesis of a required characteristic.

**(11.3) Special Methods of Frequency Division and Multiplication of Synchronizing Impulses.**

Mechanical methods of frequency division are attractive as the difficulties of avoiding the phase wander of electrical circuits do not

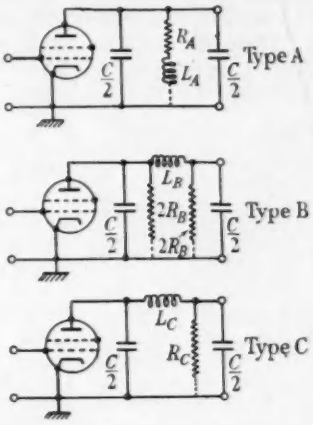



**Fig. 42.—Coupling circuits for the correction of the high-frequency characteristics of picture-frequency amplifiers**

arise. A number of methods[27] of obtaining a non-integral number of light pulses per disc revolution are available, and two are shown in fig. 43. Both arrangements use an interceptor which acts as a moving shutter. In (*a*) the scanning disc is provided with 405 holes and the region within an optical slit is imaged on a 1,500-r.p.m. interceptor with 405 holes. The optical magnification is so adjusted that one interceptor hole passes the slit in the time taken for the transit of four disc holes. By careful adjustment of the phase relationship it can be arranged that the interceptor merely opens or

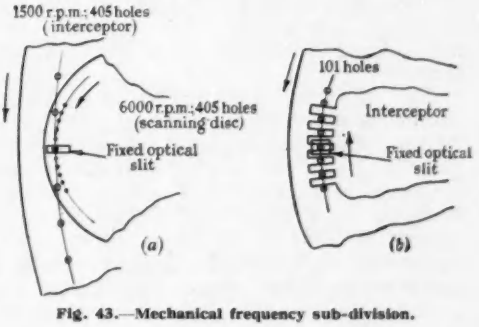



**Fig. 43.—Mechanical frequency sub-division.**

obscures the slit so that the light flux is determined entirely by every fourth hole in the scanning disc. In this way exactly 405 line

impulses are produced per four revolutions of the disc.

In arrangement (*b*) only 101 holes are punched in the disc, so that with a stationary slit only 404 line impulses would appear. The toothed interceptor acts as a secondary slit with a velocity of one slot-pitch per picture period. Thus either 403 or 405 impulses can be produced, depending on the direction of rotation of the interceptor. A fixed slit limits

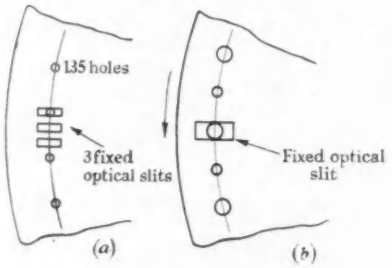



**Fig. 44.—Frequency multiplication.**

the optical field to exactly one slot-pitch, so that the light-flux cycle is repeated for the passage of every hole. This method requires an accurate interceptor and driving mechanism, as it will be seen that the effective light aperture is always controlled by the slot edges, and a simple on-off shutter action as in (*a*) is not possible.

Recent work has shown that light-pulse frequency multiplication by optical means[31] presents some advantage. In fig. 44(*a*) a disc is shown in which only 135 holes appear. This is equivalent to the removal of two of the three circles of holes in the disc of fig. 28, with some consequent gain of disc strength and stability. The normal fixed optical slit is enlarged and divided into three equal parts so that the photocell receives $3 \times 135$ impulses per revolution of the disc as in the adopted arrangement.

Fig. 44(*b*) shows a method of obtaining maximum values of components $f_L$ and $2f_L$. In any of the arrangements in which 405 holes pass the slit, per four revolutions of the disc, an additional array of half-size holes is punched between the existing holes. The resulting photocell output then contains the optimum amplitudes of fundamental and second harmonic components, which can easily be separated in a selective forked amplifier. In circumstances in which additional holes are prohibited it is possible to control the shape of the light pulse so that the required two components are of maximum values. If the hole and the slit are of the ideal form in which the aperture is fully open for an interval $kT$ and then closed for the ensuing interval $(1-k)T$, and so on, the optimum condition for generating the $q$th harmonic is that $k = (2s+1)/(2q)$, where $s$ is an integer. The preferred value of $s$ will depend upon which unwanted harmonics are most undesirable in the following selective amplifier. The opening and closing of the aperture always occupy a finite fraction of the cycle, so that in practice $kT$ is the interval between the aperture becoming half open and becoming half closed.

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# Voltage Control of D.C. Generators by Flux Diversion.

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## INTRODUCTION.

THE increasing use of direct current plant for specialised application has entailed a demand for generators having specific static or dynamic features which have sometimes been found difficult to obtain from machines designed and controlled by conventional methods. There may be, for instance, special requirements regarding the static volt-ampere characteristics of the dynamo, or the armature voltage may be required to respond rapidly to changing conditions in the control circuit.

In such instances it has been found that the application of the principle of flux diversion is sometimes capable of providing an efficient solution to the problem.

This article describes some of the advantages which voltage control by flux diversion possesses over more normal methods. It begins with a brief review of the underlying principles involved, and describes subsequently the inherent static and dynamic characteristics obtainable from generators controlled in this manner. Typical examples of the practical application of this method of control are quoted to illustrate these features.

The special characteristics obtained from a direct current generator by flux diversion will be considered under two headings, static and dynamic, the former dealing with the steady voltage generated under specified load conditions and the latter concerned with the rapidity with which the armature voltage responds to changes initiated in a control circuit.

In order to appreciate the advantages offered by flux diverter control during transient conditions, it is necessary to be fully aware of the limitations imposed by the better known methods involving main field control, and some acquaintance with the theory of electro-magnetic transients is essential. A recapitulation of this, as applicable to the main field controlled generator, is given in the following section.

### Voltage Response of Conventional Generator.

In the case of the conventional self or separately excited generator where the voltage is controlled by varying the total resistance and in consequence the current in the field circuit, the resulting rate of growth or decay of the armature flux is limited by the electrical and magnetic constants of the circuit, and the value of the flux at any instant will be proportional to the sum of all the magneto-motive forces acting in the magnetic circuit at that instant.

If the field circuit is self-inductive only, that is, if the flux produced does not link with any material capable of forming a secondary electrical circuit, the only m.m.f. acting will be due to the current in the field coils. When this flux changes in value, an e.m.f. of self-induction will act round the field coil circuit in such a direction as to tend to maintain the current, and therefore the flux, at its original figure. The value of this induced e.m.f. is equal to the rate of change of the flux linking with the turns of the field winding.

$$\text{Thus} \quad e_s = N \frac{d\phi}{dt} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where $e_s$ = e.m.f. of self-induction.
$\phi$ = the flux produced by the field m.m.f.
$N$ = number of turns of the field winding linking the flux.

The flux, as stated above, will be proportional to the m.m.f. produced by the field current,

$$\text{or} \quad \phi = KNi \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The value of the coefficient $K$ will be constant if the permeability of the magnetic

circuit remains unchanged during the change of flux under consideration.

Substituting (2) in equation (1):

$$e_s = KN^2 \frac{di}{dt}$$

for conditions of constant permeability,

or

$$e_s = L \frac{di}{dt} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Where $L$ = a coefficient termed the co-efficient of self-induction.

The sum of the e.m.f. of self-induction and the voltage required to overcome the resistance $R$ of the field circuit will at any instant be equal to the voltage $e$ applied to the circuit terminals.

Therefore

$$e = Ri + L \frac{di}{dt} \quad . \quad . \quad . \quad (4)$$

NOTE: $\frac{di}{dt}$ will be positive in value when the flux is increasing and negative when decreasing.

Therefore $\frac{di}{dt} = \frac{e - Ri}{L}$

or at the commencement of growth when $i = 0$: $\left(\frac{di}{dt}\right)_{i=o} = \frac{e}{L}$

Let $I$ = the final steady field current corresponding to a constant applied voltage $E$.

Then $E = RI$

Therefore $\left(\frac{di}{dt}\right)_{i=o} = \frac{RI}{L}$

As previously stated $\phi = KNi$

Therefore $\frac{d\phi}{dt} = KN \frac{di}{dt}$

Therefore $\left(\frac{d\phi}{dt}\right)_{i=o} = KNI\frac{R}{L} = \frac{R}{L}\Phi \quad . \quad (5)$

For a given value $\Phi$ of the flux corresponding to the final steady current $I$, the primary factors governing the inital rate of growth of flux and armature voltage are therefore the total circuit resistance $R$ and the coefficient of self-induction $L$. The ratio $\frac{L}{R}$ is termed the time constant of the circuit and must be a minimum for maximum response.

Where magnetic saturation is present the permeability of the flux path will no longer be constant and the values of the coefficients $K$ and $L$ will fall with increasing flux. The equation corresponding to (4) will in this case be:

$$e = Ri + \frac{d}{dt}(Li) \quad . \quad . \quad . \quad (6)$$

In a self-excited generator where the voltage, $e$, is supplied from the armature terminals, its value will vary during the growth of field current from a minimum determined by the residual magnetism of the machine when $i = 0$ to a maximum equal to $RI$ when the field current reaches its steady state. Between these limits the voltage $e - Ri$, which is available for overcoming the induced e.m.f. will be continuously variable and its exact value at any instant will depend upon the shape of the magnetisation curve as shown in fig. 1. It will be appreciated, therefore, that the rate of flux growth of a self-excited generator would be much slower, particularly at the commencement, than that of a separately-excited machine in which the value $e - Ri$ is greatest at this moment.

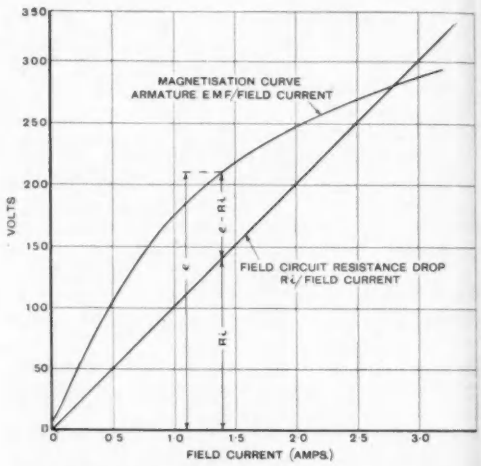


**Fig. 1.—Typical magnetisation curve showing the values of $e - Ri$ over the range of field current for a given total field circuit resistance.**

In a given machine where field coil heating limits the maximum loss which may be absorbed in the portion of the field circuit within the machine, the time constant may be reduced by arranging for an appreciable percentage of the total exciting power to be absorbed in external resistance. The field coils are consequently wound for a fraction of the available exciting voltage resulting in fewer turns per pole and a lower value for the inductance $L$.

Although the total circuit resistance necessary for the same final e.m.f. is also smaller, the reduction in the inductance is relatively greater, and the ratio $\frac{L}{R}$ is thereby reduced.

Fig. 2 indicates this effect in a normally saturated generator :

(*a*) self-excited with field coils wound for the full exciting voltage.

(*b*) separately-excited with coils wound for full exciting voltage.

(*c*) separately-excited with coils wound for one quarter of the full exciting voltage, the remaining voltage being absorbed in external resistance.

It follows from the above, therefore, that provided the field system is solely self-inductive, the limit of voltage response which can be obtained from a given separately-excited generator is determined entirely by the *power* which can be expended in the exciting circuit including all external resistance.

In a normal generator, however, the field circuit is not entirely self-inductive since the flux produced links with metallic components, notably the solid yoke, in which secondary e.m.f's and currents are induced while the value of this flux is changing. The currents flow in closed circuits in such a direction that the m.m.f's produced tend to compensate for changes made to the main field m.m.f., and thus retard the rate of change of flux. At any instant, therefore, the value of the flux will be determined by the sum of the main field m.m.f. and all the m.m.f's induced in secondary circuits, these latter being either positive or negative in relation to the main m.m.f., depending on whether the flux is decreasing or increasing at that instant.

Fig. 3, which illustrates the effect of such damping on a normal generator with a solid yoke also shows that, when high rates of response are required, the damping becomes relatively greater and imposes a definite limit on the maximum response obtainable from a given magnetic system.

A mutually inductive system in which all the flux links all conductors in primary and secondary circuits is said to be perfectly

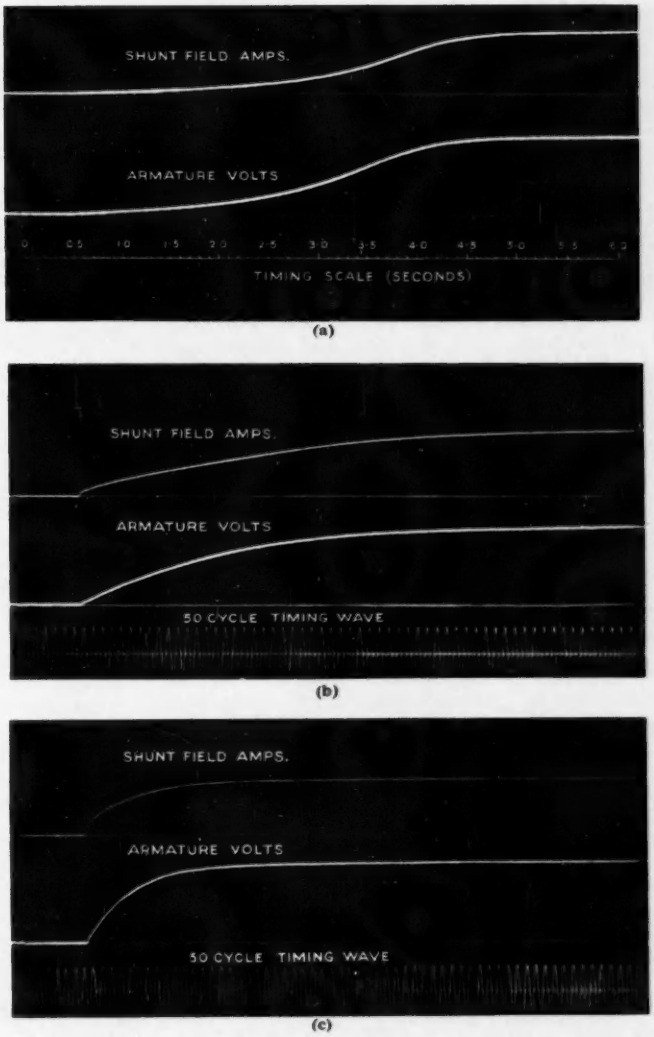


**Fig. 2.—Oscillograms showing rate of growth of armature voltage in a normally saturated generator :**

(a) Self-excited with field coils wound for full exciting voltage.

(b) Separately-excited with field coils wound for full exciting voltage.

(c) Separately-excited with field coils wound for one quarter of the full exciting voltage, the remaining 75 per cent being absorbed in external ballast resistance.

coupled, and the nett time constant is equal to the sum of the time constant $\frac{L}{R}$ of the primary and $\frac{L_1}{R_1}$ of the secondary circuit.

In a normal D.C. generator this coupling will not be perfect and the resultant time constant will be an intermediate value between $\frac{L}{R}$ and $\left(\frac{L}{R}+\frac{L_1}{R_1}\right)$

In order to reduce the damping effects of mutual couplings to a minimum, it therefore becomes necessary to reduce the value $\frac{L_1}{R_1}$ of any secondary circuit to the lowest practicable figure.

This can be done by laminating poles and, if necessary, the yoke, thus localising secondary currents to relatively high resistance circuits within individual laminations and greatly increasing the term $R_1$. It is, of course, necessary also to avoid the use of metallic spools capable of forming closed secondary circuits round the pole pieces, and care must be taken to avoid secondary paths between laminations through rivets or bolts.

Apart from damping due to the presence of mutual couplings within the iron circuit of a generator, the response of a machine is similarly affected by the presence of additional windings, *e.g.*, series field coils more or less close coupled with the main coils.

The three-field generator having self-excited, separately-excited and series coils is an extreme example of this and is commonly used for supplying power to certain rolling mill drives, marine propulsion motors, etc., where special volt-ampere characteristics are demanded. As indicated above, however, this type of machine is inherently sluggish in response and is therefore unsuitable for applications such as metallic arc welding duty where a minimum time lag is essential between the initiation or variation of current in the excitation circuit and the corresponding final armature voltage.

From the above considerations it therefore follows that the voltage response of a generator is limited by an inertia effect operating in every part of the magnetic circuit in which changes in flux linkages are necessary in producing the desired change in armature voltage. Changes in the flux linking the armature conductors and laminations of the core are, of course, unavoidable, but variations in flux linkages in the field system, and the effects of such variations, may be minimised by application of the principle of flux diversion.

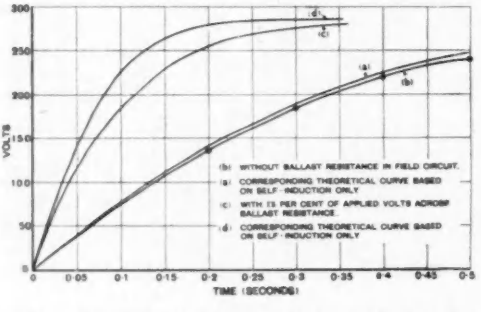
VOLTS
TIME (SECONDS)
(b) WITHOUT BALLAST RESISTANCE IN FIELD CIRCUIT.
(a) CORRESPONDING THEORETICAL CURVE BASED ON SELF-INDUCTION ONLY
(c) WITH 1½ PER CENT OF APPLIED VOLTS ACROSS BALLAST RESISTANCE.
(d) CORRESPONDING THEORETICAL CURVE BASED ON SELF-INDUCTION ONLY

**Fig. 3.—The damping effect of secondary currents induced in the solid portions of magnetic circuit. Reproduction of curves b, and c, of fig. 2 with corresponding theoretical curves indicating the rate of growth of armature voltage which would be obtained if all mutually inductive couplings were eliminated.**

## THE FLUX DIVERTER GENERATOR.

The design of the essential portions of this type of machine is adapted in practice to suit the desired characteristics, static or dynamic, and is influenced also by manufacturing considerations which largely determine constructional details.

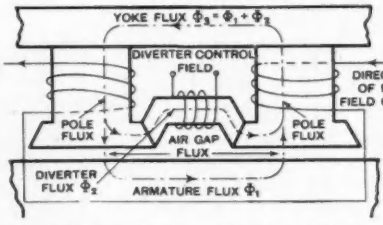


**Fig. 4.—Diagram showing main and diverter flux paths.**

In its simplest form, however, the flux diverter, as indicated in fig. 4, may be fitted to an otherwise conventional design of generator between the main pole tips. The iron core of the diverter may be laminated for the reasons stated previously in order to minimise the damping effects of eddy currents induced during transient conditions. The control winding which may consist of one or more coils is carried on the core of the diverter and, depending on the characteristics desired, may be connected in series with the armature to produce a compounding or counter-compounding effect, or may be excited from any suitable source and controlled manually or by automatic regulator.

Alternatively, the diverter may be located so as to bridge main pole tips of opposite polarity at one or both ends of the generator,

or may be connected between the tip and the yoke-end of each individual pole.

**Static Characteristics.**

The action of the flux diverter under steady conditions is as follows :—Referring to fig. 4,

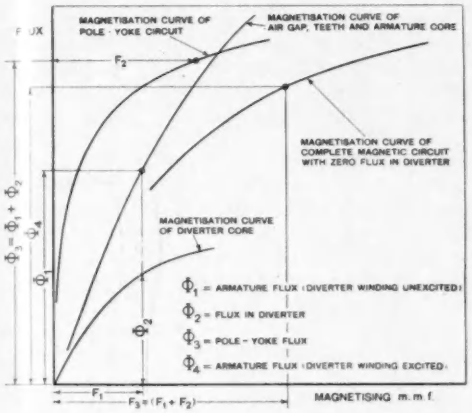
MAGNETISATION CURVE OF POLE - YOKE CIRCUIT
MAGNETISATION CURVE OF AIR GAP, TEETH AND ARMATURE CORE
MAGNETISATION CURVE OF COMPLETE MAGNETIC CIRCUIT WITH ZERO FLUX IN DIVERTER
MAGNETISATION CURVE OF DIVERTER CORE
$\Phi_1$ = ARMATURE FLUX (DIVERTER WINDING UNEXCITED)
$\Phi_2$ = FLUX IN DIVERTER
$\Phi_3$ = POLE - YOKE FLUX
$\Phi_4$ = ARMATURE FLUX (DIVERTER WINDING EXCITED)
$F_2$
$F_1$
$F_3 = (F_1 + F_2)$
MAGNETISING m.m.f.

**Fig. 5.—Magnetisation curves for pole-yoke, gap, teeth and core, and flux diverter portions of the magnetic circuit.**

it will be seen that with the control winding unexcited, the m.m.f. due to the main field produces a flux in the main poles and yoke which apart from leakage is higher than the air gap flux by an amount which is by-passed through the diverter. The e.m.f. generated by the armature is proportional to the flux $\Phi_1$ crossing the air gap, which is equal to the m.m.f., $F_1$, acting on the gap, teeth and core, divided by the effective reluctance $S_1$ of that portion of the circuit, or

$$E \text{ is proportional to } \Phi = \frac{F_1}{S_1}$$

Since the diverter bridges the main pole tips the m.m.f. acting across it is also $F_1$ and the flux through it $\Phi_2$ will consequently be $\frac{F_1}{S_2}$ where $S_2$ is the reluctance of the diverter circuit from pole tip to pole tip.

Ignoring leakage, therefore, the flux $\Phi_3$ through the main poles and yoke $= \Phi_1 + \Phi_2$ and the m.m.f. $F_2$ acting on this portion of the circuit is $S_3(\Phi_1 + \Phi_2)$ where $S_3$ is the reluctance of poles and yoke for that degree of saturation. The total m.m.f. $F_3$ produced by the main field coils is therefore equal to the sum of $F_1$ and $F_2$ as shown in fig. 5.

If the diverter control winding is now excited to produce an m.m.f., $F_1$, equal to but opposing that which acted across the diverter, the flux through it will be reduced to zero. Provided that the excitation to the main field coils remains constant, the m.m.f. $F_3$ will now be available to produce an increased air gap flux $\Phi_4$ (refer to fig. 5) which will be equal to $\frac{F_3}{S_1 + S_3}$ where $S_1$ is the reluctance of gap, teeth and core, and $S_3$ the reluctance of poles and yoke corresponding to the new degree of saturation. The effect of exciting the control winding in this manner is therefore to raise the generated e.m.f. of the machine in the ratio $\frac{\Phi_4}{\Phi_1}$ and it should be noted that the range of generated voltage which can be controlled by the diverter winding is dependent not only on the flux carrying capacity of the diverter core, but also on the ratio $\frac{F_2}{F_1}$. This point is illustrated in fig. 6 which is based on a machine otherwise similar to that referred to in fig. 5, but in which the ratio $\frac{F_2}{F_1}$ is considerably smaller owing to the provision of a pole-yoke circuit which remains unsaturated at the maximum value of flux $\Phi_3$ with correspondingly lower values of $S_3$ and $F_2$. The resulting increase in flux from $\Phi_1$ to $\Phi_4$ when the control winding is excited to the same value as before is shown to be considerably smaller.

It follows from the foregoing description that if the control winding is excited still further so as to produce an opposing m.m.f. greater than $F_1$, a flux will be produced through

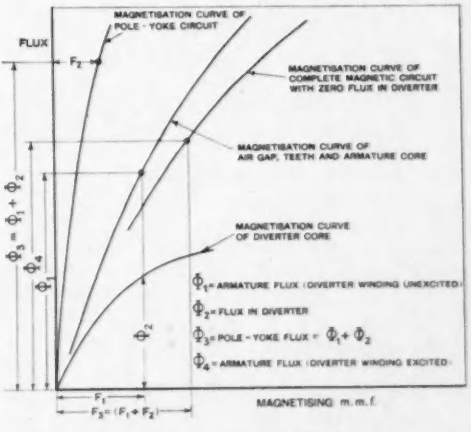
MAGNETISATION CURVE OF POLE - YOKE CIRCUIT
FLUX
$F_2$
MAGNETISATION CURVE OF COMPLETE MAGNETIC CIRCUIT WITH ZERO FLUX IN DIVERTER
MAGNETISATION CURVE OF AIR GAP, TEETH AND ARMATURE CORE
MAGNETISATION CURVE OF DIVERTER CORE
$\Phi_1$= ARMATURE FLUX (DIVERTER WINDING UNEXCITED)
$\Phi_2$= FLUX IN DIVERTER
$\Phi_3$= POLE - YOKE FLUX = $\Phi_1 + \Phi_2$
$\Phi_4$= ARMATURE FLUX (DIVERTER WINDING EXCITED)
$F_1$
$F_3 = (F_1 + F_2)$
MAGNETISING m.m.f.

**Fig. 6.—Magnetisation curves of a flux diverter generator otherwise similar to that indicated in fig. 5, but having a modified pole-yoke circuit operated at a lower magnetic density.**

the diverter in the opposite direction. This flux by completing its circuit by way of air gaps and armature will augment that due to the main field m.m.f. and a corresponding increase in armature e.m.f. will result. The maximum increase in air gap flux which can be obtained in this manner will be limited therefore by the saturation limit imposed by the dimensions of the diverter core.

Fig. 7 shows the effect of various values of control winding excitation on the open circuit characteristics of one type of flux diverter generator, the difference in spacing between the upper and lower curves being due to diverter core saturation as mentioned above.

**Practical Application of Static Characteristics.**

The inherent static characteristics which are exhibited by this type of generator can be usefully employed in a variety of applications of which the constant potential battery charging dynamo is a typical example.

The requirements are :

(*a*) That the generator shall maintain practically constant voltage under all conditions of loading between no load and a specified maximum load.

(*b*) That beyond this specified maximum load the voltage should preferably droop steeply to avoid excessive charging currents.

(*c*) That in the event of a drop in speed of the driving motor due, say, to a failure of power supply, the reverse current drawn from the battery should not demagnetise the generator field, causing the machine to run at an excessive speed as a motor, or to take a heavy discharge current from the battery. Furthermore, on restoring the speed of the driving machine, the generator should automatically restore the charging current to that obtaining before the interruption.

(*d*) That the main field polarity shall be maintained under all conditions including reversal of armature current.

It will be appreciated that a normal compound-wound generator would not be suitable for this duty since in order to obtain the characteristic (*a*) it would be difficult to obtain the final droop mentioned under (*b*). Requirements (*c*) and (*d*) could only be met by means of protective switchgear. The desired characteristics can, however, be obtained from a flux diverter generator designed as a self-excited machine, having no series coils on the main poles, but carrying series excited control windings on the diverters. For reasons previously stated, a portion at least of the pole-yoke circuit should operate at a fairly high magnetic density when the main field is excited for normal generated voltage with the armature on open circuit. Under these conditions the diverters should be designed to by-pass from the main poles a flux of approximately half the value of that entering the armature. The reluctance of the diverter circuit which determines this value is decided by the cross section and length of the iron core and the length of air gap which may be interposed in this circuit for reasons to be stated.

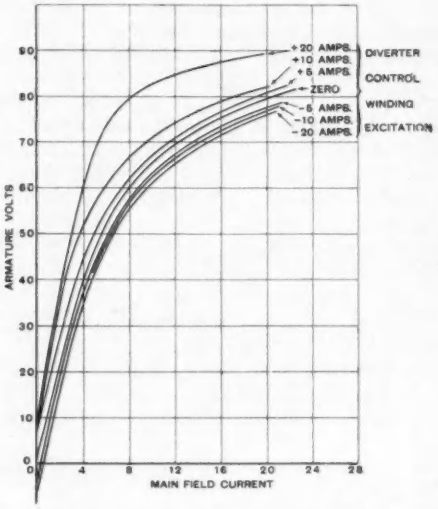


**Fig. 7.—Open circuit characteristics of a flux diverter generator with various values of positive and negative excitation applied to the diverter control winding.**

The series windings on the diverter are connected in such a manner that the m.m.f. produced by the armature current opposes that generated by the main field coils across the diverter extremities, and reduces the flux through them. At some selected value of load current the diverter flux is in this manner reduced to zero, and the flux entering the armature increased above its open circuit value as described previously. An increase in armature current beyond this point up to the specified maximum load produces a flux through the diverter in the opposite direction, and further increases the armature flux, but at this value the diverter cores become saturated so that an additional current produces a negligible increase in flux.

It will thus be seen that if this increase of armature flux between no load and the maximum load is designed to generate an e.m.f. equal to the *IR* drop in the machine and to compensate for armature reaction, the terminal voltage will remain constant over this range of load, satisfying requirement (*a*). Similarly, an armature current appreciably in excess of this specified maximum will result in a droop in the terminal voltage, since the saturation of the diverter core prevents the armature flux from continuing to increase to compensate for *IR* drop and armature reaction. Thus requirement (*b*) is met.

The exact form of the volt-ampere characteristic is largely dependent upon the shape of the magnetisation curves for the pole and yoke and diverter circuits and it is often desirable to introduce "artificial" saturation in the poles by local restricted cross-sections, and to include a certain amount of non-magnetic material in the diverter magnetic circuit in order to achieve the desired results. Fig. 8 shows one method of constructing the field system of a small heavy current generator of this type, and fig. 9 its volt-ampere characteristics.

In the circumstances stated under (*c*) the m.m.f. produced by the reversed current in the diverter windings would be in the same direction as that due to the main field coils. This would tend to increase the diverted flux beyond the value determined by no load conditions and reduce the flux entering the armature and also the generated e.m.f. In order to minimise this effect, the diverter cores are designed to operate at a fairly high flux density at no load, with the result that additional m.m.f. due to the reversed current would produce only a small increase in diverted flux and a corresponding small reduction in generated e.m.f. This would have been adjusted initially to approximate to the open circuit voltage of the battery so that the "motoring" speed of the machine under these conditions would be a little less than normal generating speed due to the *IR* drop in battery and generator and the power taken would be limited to the light running losses of generator and driving unit. Restoration of power supply to the motor would automatically return the speed of the set to normal, when the initial charging conditions would be obtained without further adjustment.

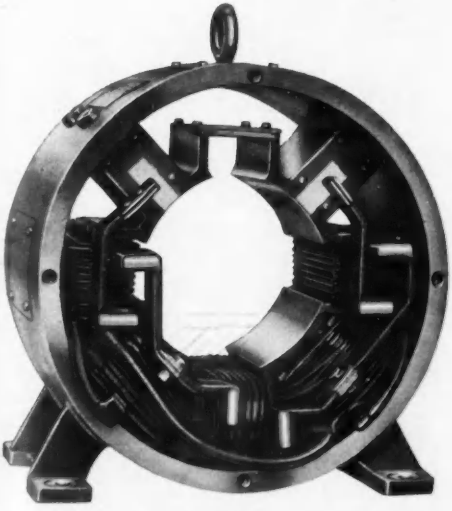

Fig. 8.—G.E.C. flux diverter generator designed for constant potential battery charging.

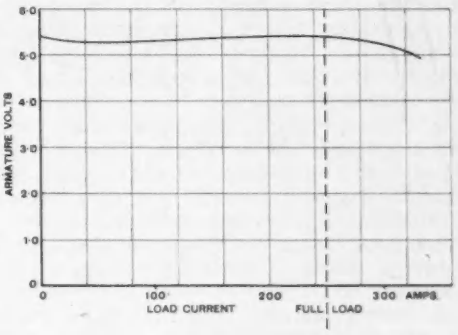


Fig. 9.—Volt-ampere characteristic of the flux diverter generator illustrated in fig. 8.

The protection afforded by the saturation of the diverter core during current reversal also ensures that the main field polarity is not affected by these conditions—an obvious requirement for battery charging generators.

**Dynamic Characteristics.**

The response of the flux diverter generator under transient conditions is governed mainly by the changes in flux which take place in the various portions of the magnetic circuit during these periods. It will be evident from the foregoing explanation of the flux distribution throughout the machine with various values of excitation applied to the diverter control winding, that the change of flux occurring in poles and yoke for a given change in generated e.m.f. is determined by the relative effective reluctances of

this portion of the magnetic circuit and the air gap and armature portion over the corresponding range of fluxes. The two sets of curves shown in fig. 10 refer to two machines having similar saturation characteristics as far as the air gap-armature circuit is concerned, but the pole-yoke portion of generator A is more highly saturated at the maximum flux $\Phi_3$ than that of generator B. For the same range of generated e.m.f., represented by $\Phi_1$ to $\Phi_4$ the maximum diverter flux $\Phi_2$ of generator B will, as indicated, be greater than that of the A machine, and in consequence the pole-yoke flux of the former will be correspondingly greater. Leakage being ignored, the pole-yoke flux will be equal to the air gap flux at the value $\Phi_4$, so that for a given change of air gap flux or generated e.m.f., machine A having the more highly saturated pole-yoke circuit would have a more nearly constant pole flux than generator B.

It follows, therefore, that the response of a machine having characteristics similar to those of example A would be very much less affected by the self and mutual induction of its main field system than that of an equivalent generator of normal design, since neglecting leakage, the total change of pole flux in the former case is $\Phi_3 - \Phi_4$ whereas in the latter it would be $\Phi_4 - \Phi_1$.

Fig. 10 also indicates another important characteristic which is peculiar to flux-diverter generators, namely that when the control winding is excited to raise the generated e.m.f. from the value corresponding to $\Phi_1$ to that represented by $\Phi_4$ the flux in the poles *falls* slightly from $\Phi_3$ to $\Phi_4$, whereas the pole flux in a normal generator under similar conditions would *increase* from $\Phi_1$ to $\Phi_4$. The e.m.f. induced in the main field coils due to the changing flux and the inductance of the field system in each case acts in a direction tending to retard the rate of change, but whereas in the case of the normal generator the effect is to retard the *rising* pole flux when the field control is operated to increase the generated e.m.f., the effect in the case of the flux diverter generator in corresponding circumstances is to retard the *falling* pole flux. In this latter case the e.m.f. induced in the field coils acts in the same direction as the externally applied field voltage and results in a momentary increase in the field current and m.m.f. which tends to maintain the pole flux momentarily at a higher value than its final steady value. The result of this is that, provided the time constants of the diverter and armature flux circuits are small compared with those of the pole and yoke flux paths, the initial growth of armature flux and generated e.m.f. will be accelerated by an amount proportional to the difference between the momentary and steady values of pole flux during the transient period. Where desirable this effect can be exploited to obtain a rapid increase in armature voltage which may actually "overshoot" the final steady value.

The above description has dealt with phenomena associated with the control of rising armature voltage. When the diverter coil excitation is decreased in value to obtain a fall in generated e.m.f. the flux in pole and yoke tends to rise to a higher steady value, but the effect of the main field inductance in this case is to cause a momentary reduction in field current and consequent retarding of pole flux growth. The decay of

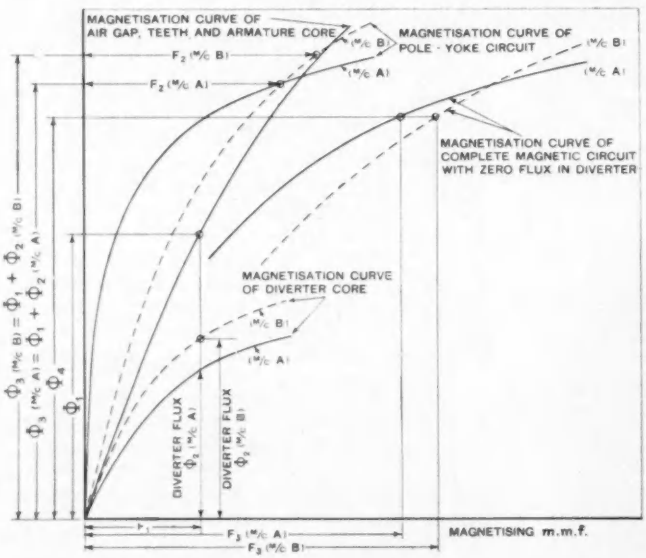
MAGNETISATION CURVE OF AIR GAP, TEETH AND ARMATURE CORE
MAGNETISATION CURVE OF POLE - YOKE CIRCUIT
MAGNETISATION CURVE OF COMPLETE MAGNETIC CIRCUIT WITH ZERO FLUX IN DIVERTER
MAGNETISATION CURVE OF DIVERTER CORE
DIVERTER FLUX
DIVERTER FLUX
MAGNETISING m.m.f.

**Fig. 10.—Magnetisation curves of the magnetic circuit of two flux diverter generators : A, having a highly saturated, and B, having a comparatively unsaturated, pole-yoke circuit.**

$\Phi_1$ = armature flux (diverter winding unexcited).
$\Phi_4$ = armature flux (diverter winding excited).
$\Phi_2$ = flux in diverter.
$\Phi_3$ = pole-yoke flux.

armature flux and generated e.m.f. is consequently accelerated and if required may be caused to "overshoot" the steady value by an amount determined by the relative time constants of the main field and diverter circuits, and by the total change in pole flux involved.

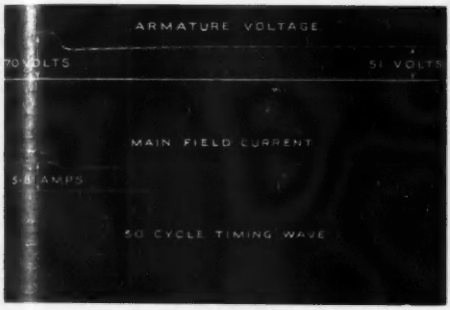


**Fig. 11.—Oscillograph record of voltage response of a separately excited flux diverter generator under open circuit conditions. Voltage reduced from 70 volts to 51 volts by reducing the excitation to the diverter control winding.**

It will be evident from the above that this inherent characteristic of the flux diverter generator may be made an important contributory factor in improving the response of voltage to rapid changes in control circuit conditions. The unavoidable inductance of the main field windings, which in a normal generator retards the rate of change of pole flux and therefore of generated e.m.f., may in the case of the flux diverter generator be employed to increase its response.

Fig. 11 is an oscillograph record of a separately excited flux diverter generator, operating on open circuit at 70 volts which is reduced to 51 volts by suddenly reducing the excitation of the diverter control winding, and indicates clearly the transient which takes place in the main field current due to the inductive effects just described. By way of comparison figs. 12 and 13 show the response obtainable from the same generator when controlled in the conventional manner by introducing resistance in the main shunt field circuit. For these tests the flux diverter was, of course, removed.

The field coils during the test recorded in fig. 12 were excited from a separate source and were wound for the full 70 volt supply. The oscillogram in fig. 13 was taken with field coils wound for 17·5 volts, the remaining 52·5 volts being absorbed in ballast or "field forcing" resistance. It will be noted that the time taken for the voltage change from 70 to 51 volts on the flux diverter generator was 0·016 sec., whereas even with considerable field forcing the time for an equivalent change in the normal machine was 0.12 sec.

As mentioned above the tendency to overshoot the steady armature voltage after a change initiated in the diverter control circuit is dependent primarily upon the rate of change of pole flux and secondarily upon the relative $\frac{L}{R}$ values of main and diverter field circuits. In applications where overshooting is inadmissible, this effect can be eliminated by operating the pole-yoke magnetic circuit at a high degree of saturation to ensure a minimum change of pole flux corresponding to the required change of generated e.m.f.

Where high rates of response are required, it is desirable to excite the main fields from a separate source, but relatively good results can be obtained from self-excited machines as may be judged by reference to fig. 14. In this it will be noticed that approximately 70 per cent of the total voltage change takes place in 0·02 sec. The remaining 30 per cent

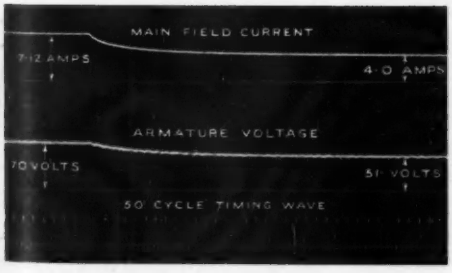


**Fig. 12.—Oscillogram of voltage response of the generator referred to in fig. 11 with flux diverter removed and machine controlled by introducing resistance in separately excited main field circuit, without additional ballast resistance.**

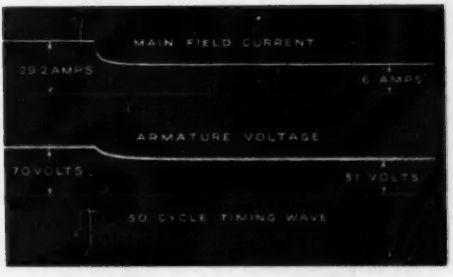


**Fig. 13.—Oscillograph record of response obtainable without the use of flux diverter but with 75 per cent of the separate excitation absorbed in ballast resistance.**

takes place comparatively slowly in 0·3 sec., but it is of interest to note that mainly due to the over-shooting tendency, the change of armature voltage during the initial 0·02 sec.

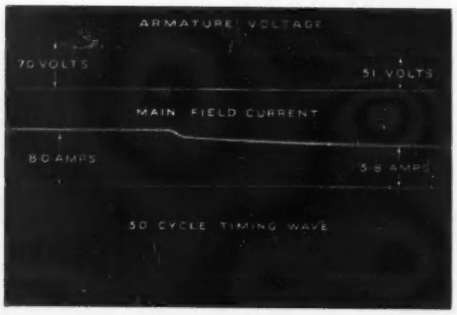


**Fig. 14.—Oscillogram showing voltage response obtainable from a generator controlled by flux diverter but with main field coils self-excited.**

is considerably greater than that of the field current which during that period achieves only 50 per cent of its total change.

**Practical Applications of Dynamic Characteristics.**

A typical instance of the practical application of flux diverter principles for the purpose of obtaining prompt voltage response is when the generator is intended to supply a rapidly fluctuating load and to maintain during these disturbances a voltage which bears a specified relationship to the load current. These conditions often arise in the case of generators and exciters supplying so called "constant current" circuits, frequently used in connection with steel works plant, but more commonly met in D.C. arc welding plant. In metallic arc welding the effective resistance of the arc circuit varies from a very low value at the instant of striking the arc to a value corresponding to the maximum arc length used, and during a welding operation fluctuates rapidly between these limits due to the passage of large and small metallic particles across the arc gap. The voltage across the terminals of a generator supplying the arc, assuming no ballast resistance in the circuit, must therefore rise and fall in conformity with these changes in resistance in order to avoid violent changes in current.

The flux diverter generator may be adapted for welding purposes by exciting the diverter control coils from the armature current in such a direction that the resulting m.m.f. acting across the diverter core "in series" with that due to the main fields increases the flux diverted. This reduces the armature flux and generated e.m.f., thereby producing a drooping volt-ampere characteristic. It is necessary in this case to limit the flux through the diverter core under open-circuit conditions in order to avoid excessive saturation when excited by the maximum current. This may be achieved by interposing a certain amount of non-magnetic material in the diverter flux path.

Alternatively the diverter may be designed to carry a second winding excited from the armature in such a direction that the m.m.f. produced would oppose that due to the main field, limiting the amount of flux diverted. On no load, when the armature voltage is a maximum the flux diverted would thus be reduced to any desired minimum. For a given increase in diverted flux between no load and full load, fewer series-excited turns would thus be required, since the opposing m.m.f. would fall with the armature voltage under load conditions and assist the series winding in increasing the diverted flux. The inclusion of a second winding on the diverter would introduce some damping due to mutual coupling with the series coils, but as the time constants of the coils concerned are small the response is not seriously affected, but may be further improved by the addition of a small ballast resistance in the shunt-excited coil circuit.

The main field coils of a flux diverter welding generator may be self-excited, in which case the response of the generator would be affected to some extent by the time constant of the field circuit. However, by so proportioning the main and diverter magnetic circuits that the armature voltage range is controlled mainly by the diverter and less by the change in main field m.m.f., which necessitates operating the pole-yoke circuit at a high degree of saturation, satisfactory results may be obtained.

Fig. 15 illustrates the dynamic characteristics of a self-excited flux diverter generator when suddenly connected to a non-inductive load, and it will be noticed that the voltage response of the machine is sufficiently rapid to limit the peak value of the current to 14 per cent in excess of the steady value.

Even faster response may be obtained by exciting the main field winding from a substantially constant voltage source and controlling the generated e.m.f. entirely by means of the flux diverter. The oscillogram reproduced in fig. 16 which was taken under conditions similar to those for fig. 15 but with

separately excited main fields, shows that the voltage in this instance falls practically instantaneously as the load is applied and the initial current "overshoot" is negligible.

## SUMMARY.

The important static characteristics of the flux diverter generator are:

(*a*) The ability to maintain a specified voltage over a given range of load, and to provide automatic protection against excessive load by a sudden droop in voltage beyond this range.

(*b*) When used in circumstances involving the possibility of current reversal, as in constant potential battery charging, the flux diverter generator is capable of supplying a substantially constant voltage over the charging current range, but unlike a normal level compound machine will operate as a motor in the event of current reversal without drawing an excessive current from the battery or accelerating above normal speed.

(*c*) The polarity of the main field system is unaffected by sudden reversals of armature current.

The response characteristics of the flux diverter generator are less subject to limitations imposed by self and mutual inductance than are those of the equivalent main-field-controlled dynamo.

Rapid adjustment of generated e.m.f., closely following current variations in the control circuit, are thus made possible without recourse to expensive laminated yoke construction or bulky and inefficient ballast resistances.

The diverter winding may be excited partially or entirely by the armature current to produce a positive or negative compounding effect, or may be connected to an independent circuit and controlled by an automatic regulator for high speed excitation or similar purposes.

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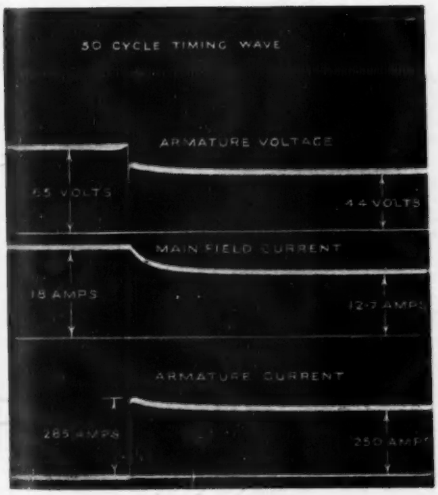


**Fig. 15.—Oscillogram of voltage response of a self-excited flux diverter generator designed for a drooping characteristic with diverter winding excited from the armature current.**

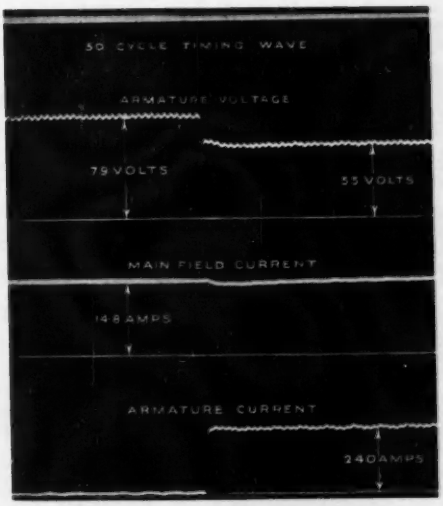


**Fig. 16.—Oscillogram showing the improved response when the main field coils of the generator indicated in fig. 15 are separately excited.**

# The Bright Annealing of Mild Steel

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## INTRODUCTION.

THE bright annealing of metals has been practised to a limited extent for a long time, two of the outstanding examples being the bright annealing of mild steel in cast iron borings and of copper in an atmosphere of steam. These two examples are interesting in so far that they differ in the method of approach. In the first the steel is protected from oxidation by being packed in cast iron borings in a heavy annealing pot or box with a well luted lid. In this way air or oxygen is, as far as possible, precluded from entering the pot, and any oxygen that does enter or may be in the box combines with the carbon in the cast iron to give an atmosphere which is essentially carbon monoxide and consequently reducing. The results obtained are very good, but the actual process leaves much to be desired on economic grounds and from the point of view of the general working conditions.

In the case of the bright annealing of copper the air inside the furnace chamber is displaced by steam, usually generated from the water used to seal the furnace. Both batch and continuous furnaces are successfully operated with this process, the chief disadvantage of which is that the copper is discharged wet from the furnace and consequently is very liable to be stained, thus to a certain extent defeating the object of bright annealing.

Despite these and other examples of bright annealing it was not until electric resistance furnaces—in which the heating is independent of gaseous products of combustion—were used on a substantial scale in industry, that serious attention was directed to the use of controlled or artificial atmospheres for the protection from oxidation of metals during annealing and heat-treatment. The subject however is one which has received very considerable attention in recent years both in the laboratory and in the works and nowadays

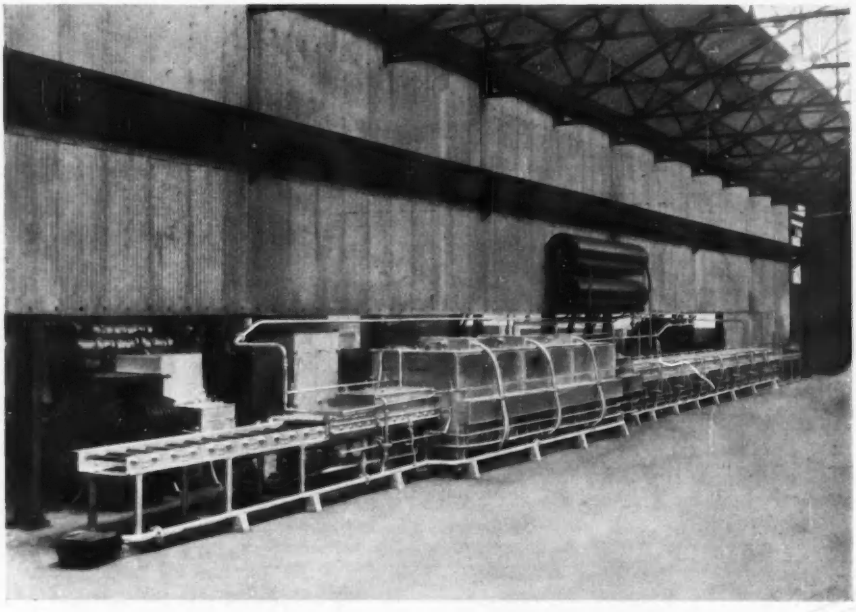


Fig. 1.—Continuous roller hearth furnace working with a controlled atmosphere.

there are very few metals or alloys which cannot be bright annealed, although with some the problem is much more difficult than with others. Thus stainless steels which contain a high percentage of chromium, and which owe their stainless properties at ordinary temperatures to an invisible film of oxide, have to be heated in an atmosphere which is absolutely free from oxygen and oxygen-containing gases. Although such an atmosphere is available commercially, the very exacting conditions which must be maintained if bright annealing is to be obtained set certain limitations on furnace design. Alloys, such as brass, which contain a volatile constituent also present special bright annealing problems. When annealed in air an oxide film is formed on the surface of the brass and the volatilization of zinc is very largely suppressed, but during bright annealing the oxide is prevented from forming and the zinc can volatilize more readily. There are ways and means of overcoming this particular trouble, but these two examples have been cited to indicate the variety of problems which had to be studied before bright annealing processes reached the present day standard. Suitable atmospheres for the bright annealing of all metals, and alloys can now be specified with certainty, but there is still room for development in the use and application of these atmospheres. Having regard to the large variation in the types of charge which have to be handled, there can be no doubt that the next few years will see important developments in the mechanical design of electric furnaces.

The advantages of bright annealing are two-fold. First, when used as the final process it is possible to retain the good surface finish produced during the previous rolling or drawing of the metal. Second, there is the saving of actual metal which is lost in the pickling solutions, in addition to elimination of the pickling process with the attendant saving in labour and floor space. The importance of these will vary in different cases according to the ultimate use for which the metal is required, but in all cases the cost of bright annealing has to be balanced against that of pickling. This in itself is not always easy because of the difficulty of assessing the value of what is usually a better product, but where the two processes are run side by side in the same plant, the older process of annealing in air followed by pickling, is invariably turned over ultimately to the bright annealing process adopted for the metal in question.

In view of the importance of mild steel, particularly from the point of view of the large tonnage involved, it is not surprising that considerable attention has been devoted to the bright annealing of this material, and this article deals more particularly with certain aspects of this subject.

## ATMOSPHERES.

As far as this country is concerned the commercially available atmospheres suitable for the bright annealing of mild steel may be divided into two main groups, namely (1) those derived from ammonia and (2) those derived from hydro-carbons such as town's gas, butane, etc.

### (1) Ammonia Derivatives.

There are two possibilities, either cracked or burnt ammonia. In the first of these, as the name suggests, the anhydrous ammonia is cracked or split into its constituents giving a gaseous mixture containing 75 per cent hydrogen 25 per cent nitrogen, which by virtue of its origin is perfectly dry. Such an atmosphere is explosive in combination with air and consequently has to be used with care. Apart from this, its high cost rules it out as an atmosphere for the bright annealing of mild steel. It is, however, used to a limited extent in the heat treatment of dead mild steel or soft iron parts for certain magnetic purposes.

Burnt ammonia is the product of burning cracked ammonia with a controlled volume of air. In this way the hydrogen content can be reduced to any desired value, 5–15 per cent hydrogen being the usual figure aimed at, the remainder being nitrogen. With a hydrogen content of the order mentioned the gas is to all intents and purposes non-explosive and there is no limit to its use on this score. In addition to the reduction in the hydrogen content the burning also results in the formation of water, and it is therefore essential that, when used for bright annealing mild steel, the gas should be dried. The intrinsic cost of burnt ammonia was initially a serious handicap to its use with mild steel, but this difficulty has to a large extent been overcome by the development of a re-circulation system which, when used in conjunction with suitable furnaces, reduces the effective cost of the atmosphere to an economic level. The capital cost of the regenerative type of ammonia burner is high and consequently is not justified for many small furnace installations. A number of both batch and continuous furnaces using burnt ammonia for the bright annealing

of mild steel are in operation. Fig. 1 shows a continuous roller hearth furnace with a regenerative ammonia burner for bright annealing straight lengths of mild steel.

**Fig. 2.—Oxidation of mild steel cooled from 720 degs. C. in flow of burnt town's gas containing free oxygen.**

From the chemical standpoint, the use of either cracked or burnt ammonia as the atmosphere for bright annealing mild steel does not present any problems. In either case it is a simple atmosphere in which, for all practical purposes, the nitrogen may be neglected, leaving the hydrogen, which is reducing, and as such prevents oxidation, or may even reduce oxide that may be on the charge. However, it will be appreciated that although the atmosphere as produced by the ammonia burner is a simple mixture of hydrogen and nitrogen, when used on the regenerative system it is possible for this to be contaminated, particularly by volatile rolling lubricants which may be on the metal charged into the furnace. For most purposes it is important that any deleterious impurities introduced in this way should be removed before the atmosphere is again admitted to the furnace. The regenerative burner has been reduced to a very simple and more or less fool-proof piece of plant and there is no reason why it should present any difficulty in any works which has some technical staff. The successful operation of the burner is mainly a matter of controlling the quantity of air which is allowed to diffuse into the gas before it is returned to the burner for regeneration, and this is largely a question of furnace design which has to be rather more elaborate than would otherwise be necessary.

Although it is possible to reduce the effective cost of burnt ammonia to an economic level, there is still room for a further reduction in the cost of the artificial atmosphere for mild steel, which is comparatively a cheap material.

These considerations have given prominence to other artificial atmospheres, the most important of which are those derived from hydrocarbons.

**(2) Hydrocarbon Derivatives.**

Of the various hydrocarbons, town's or coal gas is the most common in this country, and in view of its general availability and relatively low cost, compared with other hydrocarbons, it is not surprising that the use of town's gas as an artificial atmosphere for annealing processes has received considerable attention. The introduction of raw town's gas into annealing pots in order to prevent oxidation of mild steel has been practised in one way or another for very many years. One of the earliest patents on the subject was taken out in the latter part of the last century, although the main object in view was the reduction in the volume of gas used because of the relatively high cost of town's gas at that time. One of the main objections to the use of raw town's gas is the formation of soot on the charge, due to the breakdown of the unsaturated hydrocarbons in contact with mild steel at the annealing temperature. Many methods have been suggested for overcoming or at least reducing this to a minimum. In certain cases the results have been reasonably successful, but although raw town's gas can be classified as an *artificial* atmosphere for annealing furnaces, it can hardly be described as a *controlled* atmosphere with respect to the mild steel charge.

The usual method for reducing or eliminating trouble due to sooting is to preheat the gas so as to crack the hydrocarbons beforehand and to deposit the soot outside the furnace chamber. The cracking can be done in a separate furnace or may be incorporated in the main furnace chamber, but in either case heat has to be supplied since the cracking is an endothermic process. Also the chamber in which the cracking takes place has to be cleaned out at intervals, depending on the volume of gas treated in relation to the size of cracking furnace. But even so, the resultant atmosphere is not the ideal for mild steel since there is a danger of carburization. For this reason *cracked* town's gas is sometimes considered in connection with the annealing of high carbon steels and not mild steel.

The solution of the problem is partially to burn the town's gas with air, but the product of the combustion is a much more complex mixture of gases than the simple hydrogen-

nitrogen mixture obtained by burning ammonia. It is, however, possible, by suitable adjustment of the air/gas mixture and by a suitable design of combustion chamber, to produce an atmosphere which is controlled in relation to mild steel, and furthermore, the actual composition of the controlled atmosphere may be varied so as to produce different effects on the surface of the steel being treated. This is an aspect of bright annealing which has not received much attention hitherto, but which may have interesting commercial applications.

Partially burnt town's gas contains carbon-dioxide ($CO_2$), carbon-monoxide ($CO$), hydrogen ($H_2$), nitrogen ($N_2$) and water-vapour ($H_2O$), the proportions of which have to be controlled within certain limits if the desired result is to be obtained when the atmosphere is used in the bright annealing of steel. The determination of these limits has been the subject of extensive research work, the main results of which are dealt with in the next section.

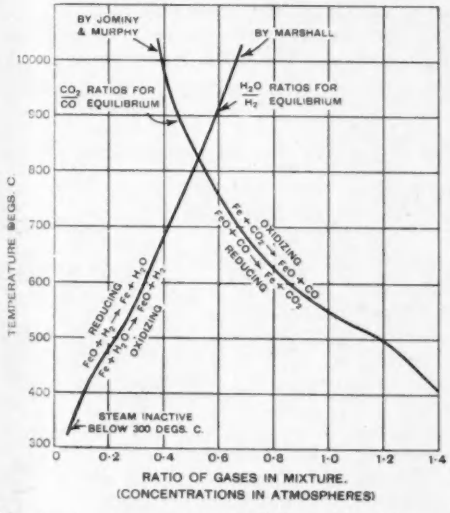



**Fig. 3.—Gas-steel reaction equilibria curves. The oxidation of iron by $CO_2$ and steam.**

## THEORETICAL CONSIDERATIONS.

The first requisite of a controlled atmosphere for the bright annealing of mild steel is a complete absence of free oxygen. Where a bright surface has to be maintained during annealing, 0·1 per cent of oxygen in a reducing atmosphere is sufficient to cause marked roughening of the surface due to alternate oxidation and reduction. Steel cooled in a flow of such an atmosphere will have an oxidised finish, since iron oxides, which form above 150 degs. C., are not readily reduced below 300 degs. C. (fig. 2).

The control of the hydrocarbon content of the atmosphere is of equal importance, since this may be a source of both carburisation and carbonisation of mild steel during annealing. Unsaturated hydrocarbons in the town's gas are completely burnt or broken down above 800 degs. C. Methane ($CH_4$) which may amount to 25 per cent of the town's gas, is not so readily broken down, and the percentage remaining in the burnt gas must be related to the hydrogen content of the atmosphere. At the annealing temperature, equilibrium conditions for equation (1) must be satisfied or the formation of more methane must be promoted.

$$CH_4 \rightleftharpoons C + 2H_2 \quad \cdot \quad \cdot \quad (1)$$

In furnaces where the controlled atmosphere comes into direct contact with the heating elements and brick-work of the furnace, which may be at a somewhat higher temperature than the material being treated, progressive carbon deposition will occur even though the atmosphere satisfies equilibrium conditions for the steel. This may give rise to difficulties in the operation of the furnace. It is thus generally advisable to ensure that the burnt gas contains no methane, and in most cases this is automatically effected by the methods employed to ensure the complete absence of free oxygen.

Partially burnt town's gas is a complex mixture of carbon-dioxide ($CO_2$), carbon-monoxide ($CO$), hydrogen ($H_2$), nitrogen ($N_2$), water-vapour ($H_2O$) and possibly sulphur compounds.

The composition of the burnt gas is controlled by the composition of the town's gas used; the ratio of air/town's gas used in the combustion; the temperature of the combustion chamber; and the use of catalysts, etc., to promote inter-gas reactions either in, or external to, the combustion chamber. For the purpose of this discussion, the effects of the sulphur compounds on the bright annealing of mild steel may be neglected. Except for the nitrogen, all the remaining constituents of this atmosphere may react with one another and with the steel at elevated temperatures, and it is necessary to consider all of these reactions and their possible effects on the surface of the steel, not only at the annealing temperature, but at all stages in the heating and cooling cycle. The reactions may be classified in two groups—(1) the

gas-steel reactions, and (2) the inter-gas reactions.

**(1) Gas-Steel Reactions.**

The possible reactions between steel and burnt town's gas are as follows:—

$Fe + CO_2 \rightleftharpoons FeO + CO.$

$$\text{Equilibrium Constant} = \frac{(CO_2)}{(CO)} \quad . \quad (2)$$

$Fe + H_2O \rightleftharpoons FeO + H_2.$

$$\text{Equilibrium Constant} = \frac{(H_2O)}{(H_2)} \quad . \quad (3)$$

$3\,Fe + 2CO \rightleftharpoons Fe_3C + CO_2.$

$$\text{Equilibrium Constant} = \frac{(CO)^2}{(CO_2)} \quad . \quad (4)$$

The concentration ratios shown with each of the above equations must equal a certain constant, which varies with temperature, if the particular reaction is to be in equilibrium. If this condition is not satisfied the reaction will tend to proceed until equilibrium is attained. The relationships between the equilibrium constants and temperature for reactions (2) and (3) as determined by Jominy & Murphy, and Marshall respectively, are shown in fig. 3.

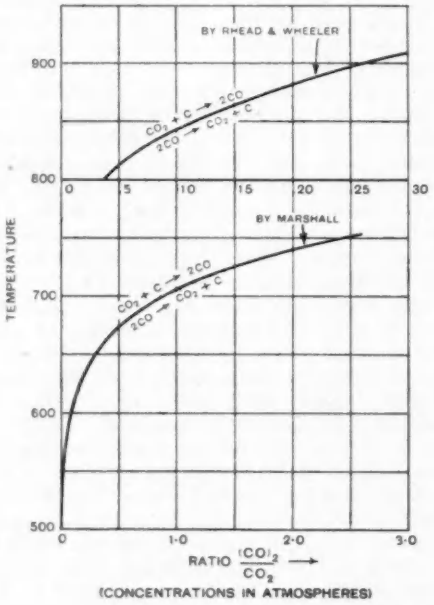



**Fig. 4.—Equilibria curves for producer gas reaction, $CO_2 + C = 2CO$.**

In equations (2) and (3), excess of $CO_2$ or $H_2O$ above the corresponding equilibrium concentrations with respect to $CO$ or $H_2$ respectively, will promote the reactions from

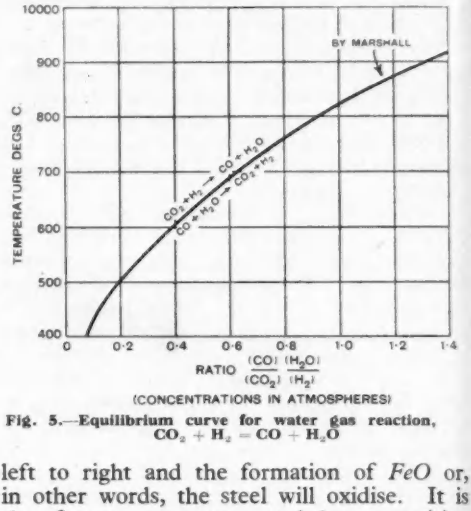



**Fig. 5.—Equilibrium curve for water gas reaction, $CO_2 + H_2 = CO + H_2O$**

left to right and the formation of $FeO$ or, in other words, the steel will oxidise. It is therefore necessary to control the composition of the burnt town's gas such that at the annealing temperature for the steel, the ratios $\frac{(CO_2)}{(CO)}$ and $\frac{(H_2O)}{(H_2)}$ are not on the oxidising side of equilibrium for reactions (2) and (3). From the equilibrium data shown in fig. 3 it will be seen that if equilibrium conditions for reaction (2) are satisfied at the annealing temperature of say 700 degs. C., then at all temperatures below this the atmosphere will be reducing to mild steel. The equilibrium constant for reaction (3), however, decreases with falling temperature, so that an atmosphere which is in equilibrium for this reaction at the annealing temperature, will be oxidising to steel at all lower temperatures.

The minimum temperature at which water vapour will oxidise steel is about 300 degs. C., and the water vapour content should theoretically not exceed the equilibrium value at this temperature. From fig. 3, the constant $\frac{(H_2O)}{(H_2)} = 0{\cdot}05$ at 300 degs. C. If it is assumed that the hydrogen content of the gas is between 10 per cent and 15 per cent, in order that the above conditions may be satisfied, the water vapour content should not exceed 0·5—0·75 per cent. In practice, however, because of the slow rate at which

this reaction proceeds to equilibrium at temperatures below 500 degs. C., with a hydrogen content of say 10 per cent, it is found possible to work with a water vapour content up to 2·5 per cent without oxidising the steel during the heating and cooling cycle. With concentrations of hydrogen greater than 10 per cent there is a corresponding increase in the water vapour content which can be tolerated without oxidising the steel. A water vapour concentration of 2·5 per cent corresponds to the vapour pressure of water at about 20 degs. C.; thus the water vapour content of the atmosphere produced by partially burning town's gas need only be reduced to the value obtained with a water-cooled surface cooler or condenser.

For the bright annealing of mild steel, reaction (4) need not be considered since the composition of the burnt town's gas is always such as to promote decarburisation, or in other words, the reaction tends to proceed from right to left. In any case, below 700 degs. C. the speed of the reaction is too slow to warrant consideration, and at higher temperatures such as are used in normalising furnaces, decarburisation of mild steel is not a problem, although the effect must be taken into consideration when dealing with medium and high carbon steels.

**(2) Inter-Gas Reactions.**

In such a complex atmosphere as burnt town's gas it is to be expected that at elevated temperatures, reactions between individual constituents of the atmosphere will take place. Two of these reactions—known as the "producer-gas" and "water-gas" reactions respectively—are of importance, since both are promoted or catalysed by the steel surface.

Producer-gas reaction

$$CO_2 + C = 2CO$$

$$\text{Equilibrium constant} = \frac{(CO)^2}{(CO_2)} \quad . \quad . \quad (5)$$

Water-gas reaction

$$CO_2 + H_2 \rightleftarrows CO + H_2O$$

$$\text{Equilibrium constant} = \frac{(CO)\,(H_2O)}{(CO_2)\,(H_2)} \quad . \quad (6)$$

The equilibrium-constant temperature curves according to Rhead & Wheeler and Marshall for these two reactions are shown in figs. 4 and 5.

It will be noted that the producer-gas reaction is similar to the carburising-decarburising reaction (4), but because of differences in the activities or "carbon-pressures" of solid carbon and carbon in solution in the steel, the equilibrium constants for the two reactions, at any temperature, are different. Below 800 degs. C., the equilibrium constant for the producer-gas reaction is lower than that for reaction (4), so that if the *CO* concentration is above equilibrium with respect to the carbon content of the steel, carburisation according to reaction (4) and carbonisation according to reaction (5) will result. To preserve a bright surface it is essential therefore that the *CO* and $CO_2$ concentrations be adjusted to produce neutral or decarbonising conditions at the annealing temperature. At temperatures below this, however, the *CO* concentration for equilibrium falls off rapidly, being zero at approximately 250 degs. C., and it is in the cooling cycle of the annealing process that the producer-gas reaction may give the most difficulty. In the presence of steel, the reaction is particularly rapid between 500 degs. and 300 degs. C.

This is illustrated in fig. 6, which shows the effect of heating mild steel specimens in a flow of burnt town's gas for ½ hour at different temperatures between 250 degs. and 700 degs. C. The deposition of carbon as indicated by the blackening of the specimens is most marked in the 350 degs.—450 degs. temperature range. In batch furnaces the rate of cooling of the charge of steel through

Composition of Atmosphere :
$CO_2$ 4.7% ; CO 9.4% ; $H_2$ 12.9% ; $H_2O$ 2.3% ; $N_2$ 70.7%

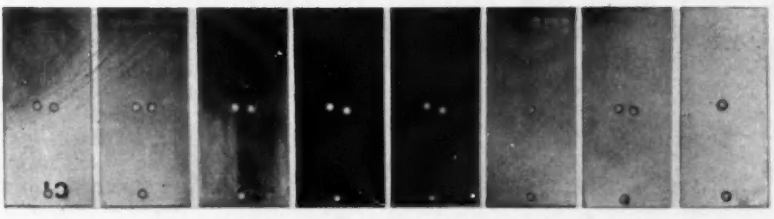



Fig. 6.—Deposition of carbon resulting from heating mild steel for ½ hour at different temperatures in a flow of burnt town's gas.

this temperature range will be slow, and if the charge is cooled in a flow of gas which is non-oxidising from the point of view of reaction (2), there will be a heavy deposit of soot on the outside surface of the charge. This can be overcome by cooling the charge under a positive pressure and not in a flow of the controlled atmosphere; in this way the total volume of gas available for the reaction is limited and the quantity of soot produced is negligible.

In continuous furnaces the rate of flow of the gas must be adjusted and the rate of cooling of the charge, particularly through this critical temperature range, must be speeded up if sooting is to be avoided. Fig. 7 shows the result of a test done to determine the effect of the rate of cooling of the steel, on the degree of sooting produced with atmospheres of different compositions. From fig. 7 it will be noted that the deposit of soot is heaviest with the atmosphere with the lowest $\frac{(CO)^2}{(CO_2)}$ ratio.

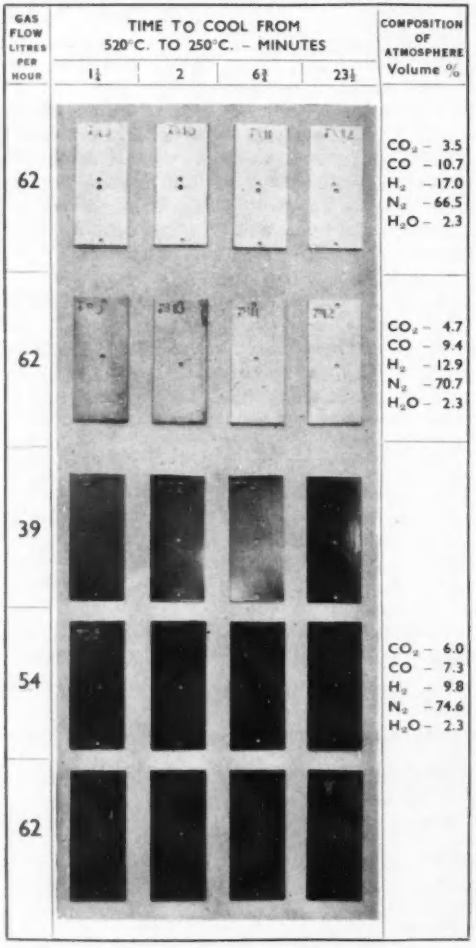
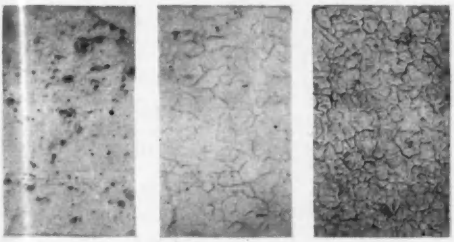



**Fig. 7.—Effect of composition and rate of flow of atmosphere on carbon deposition on mild steel cooled at different rates from 720 degs. C.**

This apparently anomalous result is explained by the fact that with the atmosphere containing the lowest percentage of *CO*, the steel surface is etched because of non-equilibrium conditions at the annealing temperature, and the surface thus produced is very active catalytically in promoting the producer-gas reaction. In addition to the steel being annealed, carbon deposition on the interior parts of furnaces, particularly in the cooling zone of continuous furnaces, should be reduced to a minimum. The water-cooled walls of this zone will remain free from sooting, but if the mechanical arrangements for conveying the material through the furnace are permanently in this zone, periodic cleaning or burning off the carbon by passing air through the furnace will be necessary.

At normal annealing temperatures the water-gas reaction may give rise to marked roughening of the steel surface if equilibrium conditions for the reaction are not satisfied. Fig. 8 illustrates the etching obtained and Table 1, which gives comparative reflectivity measurements on mild steel surfaces heated in different atmospheres, indicates the degree of roughening which can be produced. It will be noted that complete drying of the atmosphere increases the etching effect, as would be expected from a consideration of gaseous equilibria. This, together with the observations on the rate of reaction (3), indicates that it is neither necessary nor advisable completely to dry burnt town's gas for the bright annealing of mild steel. At 700 deg. C. the rate at which the reaction proceeds to equilibrium is not very rapid, but as the steel surface becomes etched, so its catalytic activity increases, and with suitable atmosphere compositions it is possible to obtain considerable roughening even at this temperature. Where a bright, polished surface has to be maintained during annealing, the water-gas reaction is of most importance when the material is batch annealed either in coils or packs of sheets. In both cases it is the outer surfaces of the charge which receive the full effects of non-equilibrium conditions, but some penetration of the gas between individual sheets or coil turns takes place. Due to the slow rate of reaction at ordinary annealing

temperatures for mild steel, the atmosphere penetrating the coil turns, if originally out of equilibrium, will continue to etch, the effect decreasing as the centre of the strip is approached. Non-uniformity of surface finish will result, and in many cases this is of more concern to the manufacturer than is the



720°C. 820°C. 920°C.

(Magnification × 100).

**Fig. 8.—Etching of polished mild steel heated for 15 minutes at various temperatures in burnt town's gas.**
Analysis of gas: 4.7 per cent $CO_2$, 9.4 per cent CO, 12.9 per cent $H_2$, 2.3 per cent $H_2O$, 70.7 per cent $N_2$.

maintenance of a certain degree of surface finish. The solution lies in arranging the charge so as to permit the free circulation of the atmosphere over every surface of the steel; preventing penetration of the atmosphere between turns or sheets by employing very tight coiling or close packing; ensuring that the atmosphere satisfies all equilibrium conditions at the annealing temperature. The latter method is to be preferred and with experience presents no difficulty. The bright annealing of single strips of mild steel in continuous furnaces does not present this difficulty since the whole of the surface of the material is exposed to the controlled atmosphere. In many cases the production of an etched or "toothed" surface prior to plating or coating processes may be desirable, and such surfaces may well be obtained by annealing in a suitable atmosphere. The application of burnt town's gas to this particular field has yet to be fully investigated.

In addition to maintaining a bright surface during annealing, burnt town's gas may also be employed successfully for the clean-up, during annealing, of rusty or oxidised steel. It should be noted, however, that the reduced surfaces thus produced are very active catalytically, especially those produced from rust marks, and although it is obvious that such defects should be avoided, in cases where they are inevitable care must be taken that local carbon deposition during cooling is eliminated.

Rolling oils play a very important part in bright annealing processes. Surface deposits due to the dissociation of oil vapours in the heating chamber may be serious unless the oil vapours are removed quickly from the annealing pot or furnace. Mineral and rape oils present little difficulty, but heavy and soluble oils often leave carbon deposits which are difficult to remove by ordinary cleaning methods. In such cases burnt town's gas is the most suitable atmosphere to use, since the $CO_2$ and $CO$ contents can readily be adjusted to produce decarbonising conditions, and thus reduce staining due to this cause. It is always advisable, however, to have the minimum amount of oil on the surface of the steel, and in many cases the steel is mechanically wiped after rolling. But however ideal the rolling oil, from the point of view of bright annealing, all the advantage is lost if the steel is allowed to stand for any length of time between the rolling and annealing operations. Atmospheric oxidation of the lubricant gives rise to gummy compounds which may result

TABLE 1.

**Effect of Time and Temperature on the Etching of Polished Mild Steel Surfaces in Burnt Town's Gas Atmospheres.**

**Reflectivity Measurements.**

| Composition of Atmosphere. | | | | | Reflectivity (percentage of untreated surface) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 720 degs. C. | | 820 degs. C. | | 920 degs. C. | |
| $CO_2$ | CO | $H_2$ | $N_2$ | $H_2O$ | 5 mins. | 15 mins. | 5 mins. | 15 mins. | 5 mins. | 15 mins. |
| 3.5 | 10.7 | 17.0 | 66.5 | 2.3 | 96 | 90 | 87 | 80 | 74 | 66 |
| 4.7 | 9.4 | 12.9 | 70.7 | 2.3 | 94 | 86 | 76 | 70 | 64 | 57 |
| 4.8 | 9.7 | 13.2 | 72.3 | — | 96 | 80 | 67 | 59 | 48 | 43 |
| 6.0 | 7.3 | 9.8 | 74.6 | 2.3 | 87 | 80 | 66 | 56 | 49 | 36 |

in pronounced staining of the annealed material. Some study of oil with reference to its function in the cold working processes and to its effect during the subsequent annealing has been made, but little conclusive information has so far been obtained. Much work still remains to be done in this field, but there can be no doubt that whatever the atmosphere used, the best bright annealing is obtained with steel which is either dry rolled, or alternatively de-greased. Since, however, neither of these alternatives is, in general, a practical proposition, the use of burnt town's gas as the annealing atmosphere has advantages over other atmospheres which do not contain $CO_2$ or $CO$ which react with carbonaceous residues and promote their removal from the surface of the steel.

Whilst equilibria for the reactions discussed have been thoroughly investigated by various workers, they apply to more or less ideal conditions. The evolution of gases, especially water vapour, from the linings of continuous furnaces, the presence of rolling lubricants and the material of annealing containers, may appreciably affect the composition of the controlled atmosphere. Very often the most suitable conditions for a particular plant can be determined only by "trial-and-error" methods. On the other hand, the importance of studying gas-metal equilibria cannot be too strongly emphasized, since such knowledge serves as a very valuable guide to correct working conditions and to a complete understanding of all the changes that may be taking place during the annealing process.

From a consideration of theoretical data and practical experience, the composition of burnt town's gas for the bright annealing of mild steel at temperatures in the region of 700 degs. C. should be as follows :—

| | |
|---|---|
| $CO_2$ | 3·5—5·5 per cent. |
| $CO$ | 10·5—8·5 per cent. |
| $H_2$ | 15·0—10·0 per cent. |
| $H_2O$ | < 2·5 per cent. |
| $O_2$ | Nil. |
| $CH_4$ | < 0·5 per cent. |
| $N_2$ | Remainder. |

In general there is no difficulty in partially burning town's gas so that the resultant atmosphere satisfies the composition given above. There are, however, certain localities in which the town's gas contains a higher $CO_2$ content than normal, and in these instances burnt gas of the composition specified cannot be produced. Provided, however, the equilibrium constants for the various reactions concerned lie within certain limits, the burnt town's gas will still be suitable as a bright annealing atmosphere for mild steel. The recommended limits for the equilibrium

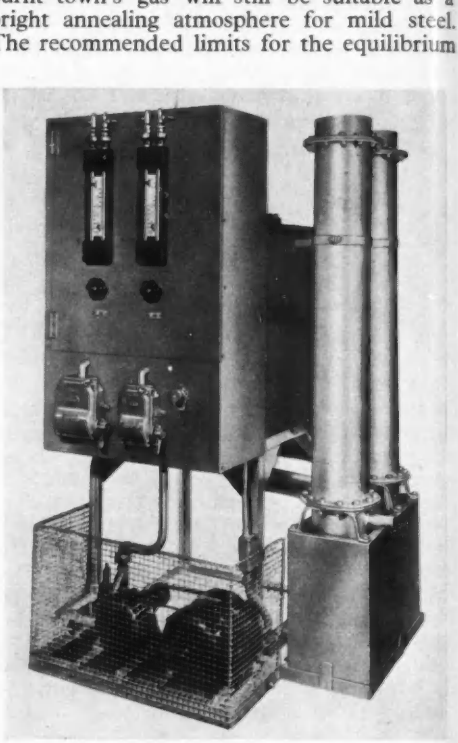


**Fig. 9.—300 cu. ft. per hour town's gas burner.**

constants at 700 degs. C. are as follows :— Concentrations are expressed in atmospheres.

Reaction 1 $\dfrac{(CH_4)}{(H_2)}$ —— $< 0{\cdot}05$

„ 2 $\dfrac{(CO_2)}{(CO)}$ —— $< 0{\cdot}65$

„ 3 $\dfrac{(H_2O)}{(H_2)}$ —— $< 0{\cdot}2$

„ 5 $\dfrac{(CO)^2}{(CO_2)}$ —— $0{\cdot}2—0{\cdot}8$

„ 6 $\dfrac{(CO)\,(H_2O)}{(CO_2)\,(H_2)}$ —— $0{\cdot}5—0{\cdot}7$

The composition of the burnt gas will depend on that of the town's gas used and on the temperature maintained in the atmosphere generator. It is therefore advisable to have control over the inputs to the generator of both the air and the town's gas. The ratio

of air to gas supplied to the generator to obtain a burnt gas within the above limits of composition is usually 2 to 2½ volumes of air to 1 volume of town's gas, although in districts where the $CO_2$ content of the town's gas is high (up to 6 per cent) this ratio may have to be reduced below 2 to 1.

When town's gas is burnt with air the volume of the resultant products of combustion is very approximately equal to the volume of air used, so that if the ratio of the air to town's gas supplied to the burner is of the order of 2 the volume of the controlled atmosphere is about twice that of the town's gas used. This fact is reflected in the cost of the burnt town's gas.

Town's gas has been considered as the hydrocarbon from which the controlled atmosphere is produced, but in certain districts where a supply of town's gas may not be available other hydrocarbons such as butane may be used. The same general considerations regarding gas-metal and inter-gas reactions apply as have already been discussed for town's gas. There is, however, one interesting difference in so far that, since butane is a much richer hydrocarbon than town's gas, a much higher air/butane ratio is necessary to produce the required controlled atmosphere. In practice this is about 15 volumes of air to 1 volume of butane. This results in a corresponding increase in the volume of controlled atmosphere produced per volume of butane used, and to a certain extent counteracts the higher cost of butane in relation to that of town's gas.

Hydrocarbons such as butane also have the added advantage that they are usually free from sulphur compounds which, as will be mentioned later, have to be taken into consideration in the case of town's gas.

### TOWN'S GAS BURNER.

The essential features of a town's gas burner are: accurate control and means for adjusting the air/gas ratio; the design of the combustion chamber; suitable condensers for cooling and removing the excess water vapour produced during combustion. Although there are many ways by which the volumes of air and gas supplied to the burner may be accurately controlled, these are in principle the same and amount to the use of suitable flow meters in the air and gas lines. In a small burner with an output of 300—400 cu. ft./hour, such as is shown in fig. 9, orifice gauges are used, the volumes of gas and air being indicated by the U-tube gauges mounted on the front of the panel. The valves for regulating the flows are below the gauges. The measured volumes of air and gas pass on to a small blower where they are thoroughly mixed before delivery at a low positive pressure to the burner nozzle, which, in this instance, is situated at the top of the combustion chamber. The combustion chamber, which is lined with refractory, has to be so designed that the temperature attained inside is such that the various reactions necessary to ensure complete removal of oxygen, elimination of hydrocarbons and the balanced composition of the final atmosphere take place. These reactions are promoted by the use of suitable catalysts with which the combustion chamber is packed. All these considerations have to be taken into account in arriving at the size of the chamber for a given output of the controlled atmosphere, and in view of this it will

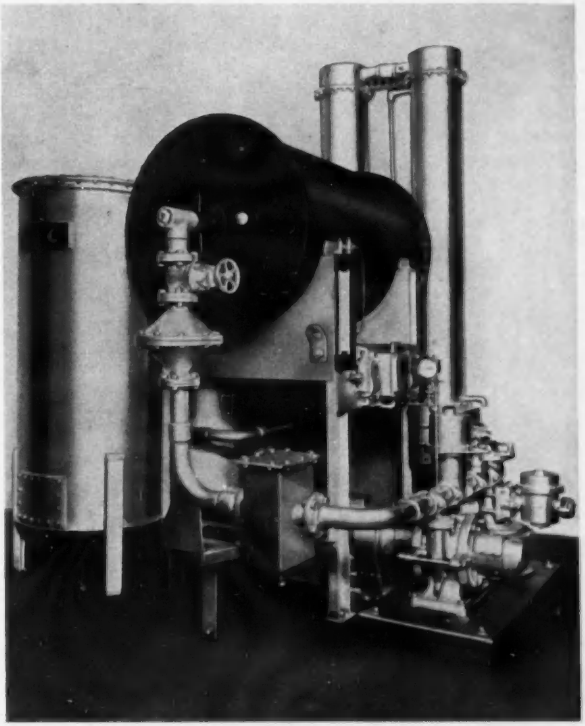
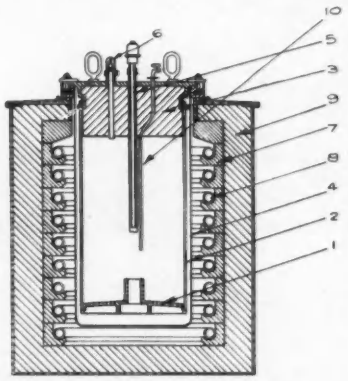


Fig. 10.—1,000 cu. ft. per hour town's gas burner.

be appreciated that the output from any particular burner must be maintained between fairly close limits if the correct atmosphere is to be obtained.

From the combustion chamber the atmosphere passes to the condensers, shown to the right of fig. 9, where the excess water is removed and the water vapour content of the atmosphere reduced to a value corresponding to that of the vapour pressure of water at the temperature of the cooling water used. Since the water vapour content of the issuing gas should not exceed about 2·5 per cent which corresponds to a temperature of about 20 degs. C., it is important that an adequate supply of cooling water to the condensers should be maintained. The condensers are usually of the open water seal type, which has an advantage that the depth of the water in the seal can be so arranged as to provide an efficient safety valve for the plant.

For many purposes, and for continuous furnaces in particular, considerably larger outputs than the 300/400 cu. ft. per hour of controlled atmosphere delivered by the burner shown in fig. 9 are required. In some cases where the demand varies over a wide range, it is possible to use a number of small burners which are brought into operation as required. On the other hand, where the demand is reasonably constant, a single large burner is preferable, and fig. 10 shows a burner with a nominal output of 1,000 cu. ft./hour. This in principle is the same as the smaller burner, the chief differences being the method of controlling the air/gas ratio and the use of a horizontal in place of a vertical combustion chamber. Some of the details of the burner



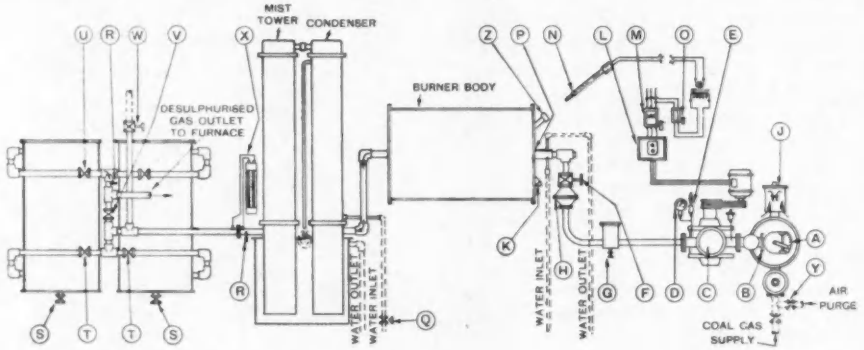

**KEY.**

| | | | |
|---|---|---|---|
| **1** | Cast base plate. | **6** | Valve or gas outlet. |
| **2** | Nickel chromium suspension rods. | **7** | Firebrick lining. |
| | | **8** | Heating elements. |
| **3** | Thermally insulated cover. | **9** | Thermal insulation. |
| **4** | Cylindrical annealing pot. | **10** | Gas inlet pipe. |
| **5** | Pyrometer sheath. | | |

**Fig. 12.—Section through vertical cylindrical annealing furnace.**

are shown in the schematic arrangement, fig. 11.

From this it will be noted that the preliminary ignition of the burner is by means of an electric poker which has to be left in position in the burner until the chamber is sufficiently hot to maintain combustion of the otherwise non-inflammable air/gas mixture.


MIST TOWER
CONDENSER
BURNER BODY
DESULPHURISED GAS OUTLET TO FURNACE
WATER OUTLET
WATER INLET
WATER INLET
WATER OUTLET
AIR PURGE
COAL GAS SUPPLY
U R W V X Z P N L M O E J K H R S T T S Q G F D C B A Y

**KEY.**

| | | | | | |
|---|---|---|---|---|---|
| **A** | Air-gas mixing control. | **J** | Air filter. | **R** | Gas sampling cocks. |
| **B** | Automatic gas-air mixer. | **K** | Burner sight glass. | **S** | Drains—ore beds. |
| **C** | Rotary compressor. | **L** | Compressor-contactor push button. | **T** | Ore bed inlet—change over valves. |
| **D** | Pressure gauge 0—100in. w.g. | **M** | Compressor-switch fuse. | **U** | Ore bed outlet—change over valves. |
| **E** | Gas-pilot flame. | **N** | Electric igniter. | **V** | Ore beds by-pass valve. |
| **F** | Air-gas throttle valve. | **O** | Switch fuse for igniter. | **W** | Waste pipe valve (starting up). |
| **G** | Drain-oil trap. | **P** | Burner nozzle. | **X** | Flowmeter. |
| **H** | Flame trap. | **Q** | Shut off valve-cooling water supply. | **Y** | Air purging line. |
| | | **Z** | Sealing cap—igniter hole. | | |

**Fig. 11.—Schematic arrangement of 1,000 cu. ft. G.E.C. controlled atmosphere plant.**

In some cases it is necessary to do further processing of the atmosphere from a town's gas burner, and in this connection the most important considerations are de-sulphurisation and drying.

Fig. 13.—Charge of mild steel strip loaded on base casting and suspended from pot head.

The quantity of sulphur, usually present as sulphuretted hydrogen, sulphur-dioxide and organic sulphur compounds, in the burnt town's gas, depends on the sulphur content of the original gas, and although this could be removed before the gas is burnt, it is more general to purify after burning. While there are very few applications in which the presence of sulphur compounds in the controlled atmosphere is an advantage, the necessity for de-sulphurization will depend on the particular application. Thus in cases where the atmosphere comes in contact with the nickel-chromium heating elements of the furnace, removal of sulphur, and $H_2S$ in particular, is essential. There are two methods in general use, namely, the absorption of $H_2S$ by means of bog iron ore, and the absorption of all sulphur compounds by means of activated carbon. Figs. 10 and 11 show bog ore boxes. From fig. 11 it will be seen that two ore boxes are used, one being in use, while the other is being recharged with fresh ore. A similar arrangement is used when de-sulphurizing by means of activated carbon.

As far as mild steel is concerned, as has already been explained, further drying of the gas below the 2·5 per cent water vapour level is neither necessary nor advisable. But for purposes where a drier gas is required, the water vapour content may be reduced by means of activated alumina, silica gel or refrigeration.

### ANNEALING FURNACES.

The bright annealing and normalising of mild steel in continuous furnaces has already been mentioned in connection with the use of burnt ammonia as an artificial atmosphere. The same type of furnace (fig. 1) is used with burnt town's gas, although the gas is not used again but simply blown to waste from the open ends of the furnace. This means that the design of the ends of the furnace can be simplified, but even so, it is necessary to ensure that infiltration of air into the furnace is reduced to a minimum. It is also important that the flow of gas out of the ends should be balanced; and the points at which the atmosphere is introduced into the furnace so as to ensure uniform distribution throughout a chamber which, including the cooling zone, may be over 100 feet long, are obviously very important.

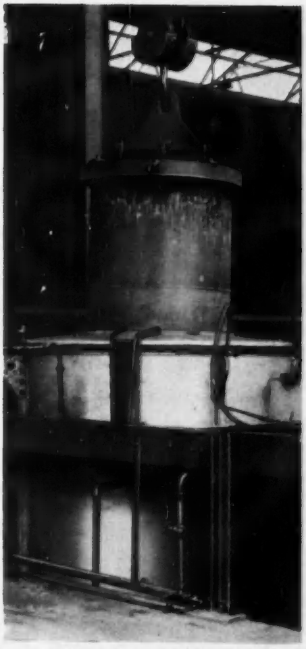


Fig. 14.—Charging of annealing pot into vertical cylindrical furnace.

Continuous furnaces can be and are used for annealing mild steel, but it is for

bright normalising that they are most useful, since this process calls for fairly rapid cooling of the steel from the heat-treatment temperature. In addition to the bright normalising of bright or clean strip, by the use of a suitable atmosphere it is possible to bright normalise hot rolled strip which has an oxidised surface before it enters the furnace. Continuous furnaces are also used for the bright heat-treatment of steel tubes.

Although continuous furnaces are used for the purposes mentioned above, the bulk of the mild steel produced in this country is annealed in batch type furnaces.

One of the most successful batch bright annealing electric furnaces in use in this country is the vertical cylindrical pot furnace which is designed primarily for charges of strip in coil. A vertical section through such a furnace is shown in fig. 12 which also refers to the main features of the plant.

The coils of strip are stacked on the base casting which is suspended from the pot head by three suspension straps as shown in fig. 13. The charge is lowered into the light weight pot envelope and, after bolting down, the whole is lowered into the furnace as shown in fig. 14. The actual seal between the envelope and the pot head is a water-cooled rubber ring, which is perfectly gas tight. The use of this particular type of seal is very effective when working with a controlled atmosphere, the flow of which may be reduced to the very minimum ; in fact, during the heating part of the heat-treatment cycle, 50 cu. ft. per hour or even less is sufficient to ensure bright annealing of the mild steel charge. As has already been mentioned, with burnt town's gas as the controlled atmosphere for mild steel, there is a danger of carbon deposition during the cooling of the charge, particularly in the region of 500 degs. C. This can be reduced to negligible proportions, by not having a flow of the controlled atmosphere through the pot during this stage of the heat-treatment cycle. It is, however, usual to maintain a positive pressure of the atmosphere inside the pot so as to make up for the contraction in the volume of the atmosphere during cooling. For this purpose the vertical cylindrical pot type furnace with the water-cooled rubber seal to the pot is ideal, since it is possible to ensure that there is no flow of gas during cooling. Because of the low gas consumption with this type of furnace equipment, one small town's gas burner will provide the controlled atmosphere for 2 or more furnaces, the actual number depending on the heat-treatment schedule adopted by any particular plant, for in addition to the flow of gas which is used during the heating of the charge, it is also advisable to have some gas available for purging the pot of air prior to charging it into the furnace.

Fig. 15 shows a typical vertical cylindrical furnace installation for bright annealing mild steel strip in a burnt town's gas atmosphere. Two small burners can be seen on the left of the illustration. One of these provides sufficient controlled atmosphere for this annealing plant, the second burner being maintained as a stand-by.

**Fig. 15.—Vertical cylindrical furnace installation for bright annealing mild steel.**

# Electricity in Paper Mills.

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PART I.*

*This paper was read before the North-Eastern and North-Western Centres of the Institution of Electrical Engineers during the Session 1941, and was awarded a Premium. It is reprinted from the Journal of the Institution.*

## INTRODUCTION.

THE paper-making industry in this country has in normal times an annual production of 2·3 million tons, consumes nearly 1·75 million tons of coal per annum, and employs about 60,000 to 70,000 people.

Paper in various forms is used extensively in the electrical industry for insulation purposes, and when made up with the non-hygroscopic fillers has a high electric strength. It is also employed as a binder for micanite.

The suitability of paper for electrical purposes has been investigated by the National Physical Laboratory, and papers on this subject have been published in the Journal of the Institution of Electrical Engineers.[1] The present paper deals only with the electrical equipment of the paper mill, and gives a brief general description of the manufacturing process, as the latter is varied to suit every one of the numerous grades and types now available.

The most recent paper presented on this subject will be found in the Journal of the Institution of Electrical Engineers.[2] Although sectional drives were known, only a few were running and their performance was keenly watched; since then the application of electricity to the paper-making industry has been energetically pursued during the past 10 years, and a number of developments have taken place.

* Note—The numerical references in the text are to the Bibliography, which will be published with Part II of this article.

## (1) A SURVEY OF PAPER-MAKING PROCESSES.

The basis of all forms of paper is cellulose, in the form of wood, rags or esparto grass. Paper mills in this country, with very few exceptions, receive wood cellulose in the form of pulp, which is prepared on sites in or near the forests, where the natural advantage of plentiful water supply can be utilized both for manufacture and for cheap power supply.

Pulp is produced by two methods, namely grinding logs into flour, or "digesting" wood chips with acid or alkali. This latter process takes about 9 hours and yields a pulp which is free from resins and lignins, consisting of fibres about 1 to 3 mm. long. The fibres from the second process, and the wood from the first, are made up into bales of 3 or 4 cwt., and form the bulk of the raw material of the industry. High-grade paper is made from rags, esparto grass or sulphite pulp as described above, the two former materials requiring to be chemically treated and cooked with steam to get them into suitable form for paper making.

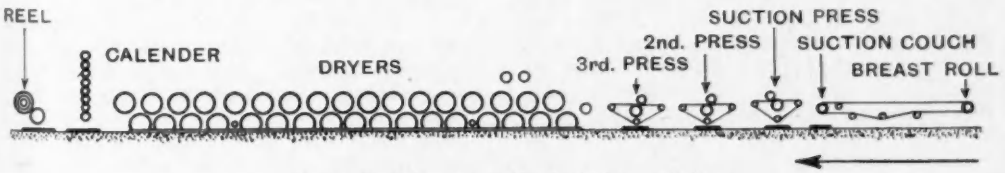


**Fig. 1.—Typical paper machine in diagrammatic form.**

The first stage in the actual paper-making process is that of "beating" or breaking up the raw pulp and thoroughly separating the fibres. Suitable proportions of chemical pulp and wood flour are mixed with water, fillers and dyestuffs, and are placed in the endless trough of the beating machine. A motor-driven roll, which has axial bars on its surface, is arranged to clear a similar set of bars mounted on a bedplate at the bottom of the trough, so that

the pulp undergoes a brushing action between the two sets of bars. In addition to undergoing a thorough mixing and separating action, the fibres form a gel, are hydrated and rendered capable of being felted together into a sheet of paper. The period, intensity and pressure of the beating process has a marked effect on the finished product; for instance, the difference between grease-proof paper and blotting paper is entirely due to control of beating. On leaving the beaters, the mixture, which contains about 6 per cent of solids, is passed into a chest, where it is agitated continuously. From this point the process becomes continuous. Leaving the chest, the "stuff" is pumped into a refiner for a continuation of the brushing process. The refiner resembles the beater in its action, but its moving bars are carried on a conical rotor working within a barred casing. Thus a still further separation of the fibres is effected. A detailed description of the beating process has been given by S. Milne.[3]

A chest receives the refined "stuff," which is now further diluted via the stuff pump with water to a solid content of 0·5 per cent. Finally, after screening to reject any lumps or bundles, the stuff enters the flow box of the paper machine proper. The function of the paper machine is to form the stock into a sheet by abstracting the water from it.

The time for the whole process, from the first formation of the sheet to the reeling up of the finished paper, is usually less than one minute.

Fig. 1 shows a typical paper machine in diagrammatic form, and fig. 2 an elevation of a modern 3-roll machine, and it will be noted that the process has three distinct stages, namely:

*Stage* 1.—The couch section, where the sheet is formed and drained.

In this section the stuff leaves the flow box and passes in an even stream on to an endless wire-mesh band, supported on rolls to give a flat surface. Water drains through the band, being assisted by the capillary attraction of supporting rolls, and this process is aided towards the end by a number of suction boxes located below the wire. Finally, the wire band passes round a perforated suction roll which is also used to impart the drive to this section.

To promote the matting or felting of the cellulose fibres, the whole of the couch section is oscillated laterally for about 0·5in. at a frequency of 2 or 3 per sec.

At the end of the couch section the sheet is recognizably paper, though it has still a moisture content of 80 per cent. It is capable of supporting itself over a short length and is transferred to the next section.

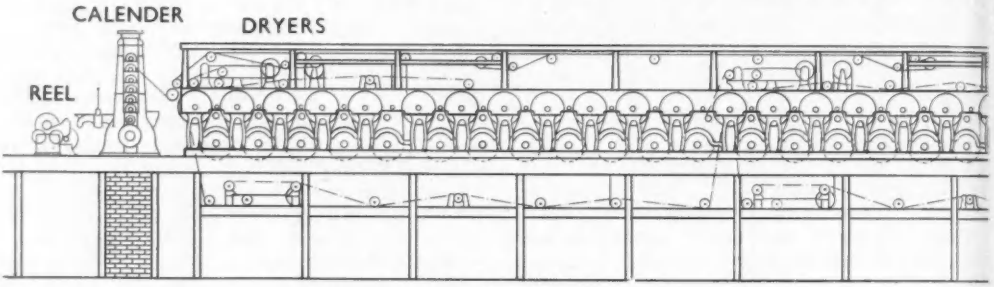


**Fig. 2.—Elevation of 3-roll machine.**

*Stage* 2.—In the 2- (or more) press sections the sheet is supported on a woollen felt and squeezed between pairs of rolls, which reduce the moisture content to about 70 per cent. As no more water can be removed by mechanical pressure without damage to the sheet, this now passes on to the next stage.

*Stage* 3.—The removal of the remaining moisture by heat. The dryer section is the largest in the machine and consists of numerous steam-heated cylinders, arranged in two tiers, over which the paper is passed, with the result that its moisture content is reduced to about 8 per cent. The calenders which follow the dryer stage consist of a vertical stack of 8 to 10 chilled cast-iron rolls, which the paper enters at the top. Passing downwards between each pair of rolls, the paper is subjected to increasing pressure, which rises to about 250 lb. per inch of width at the lowest roll. The drive to all rolls above the lowest is by friction only, and the slight slip has the effect of polishing both sides of the paper.

Finally, the paper passes to the reeler, and is wound into reels of about 4ft. diameter.

In a typical high-speed machine an indiv-

idual fibre traverses a total length of about 800f . in undergoing the whole series of proc sses. Details of paper machines and auxi ary equipment are given in papers by Wor y Beaumont and L. N. Burt,[4] and W. H. Orr.[5]

Th e finishing processes which follow are agair intermittent. Where a high surface finish is required, the paper is passed through a supercalender which has alternate chilled-iron and compressed cotton or paper rolls. The machine is considerably larger than the machine calender, but its construction and purpose are similar. Following the supercalender the reels are passed through a winder and slitter where they are trimmed, slit to the required width and re-reeled. If the final product is in sheet form, a guillotine is employed to cut them from the reel.

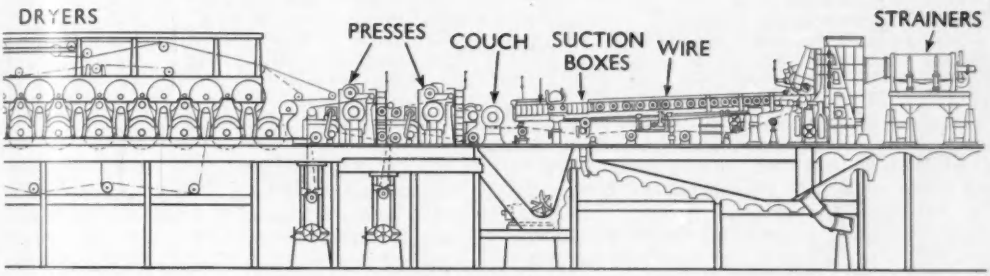


**Fig. 2.—(continued).**

### (2) SPECIAL PROBLEMS OF POWER GENERATION AND DISTRIBUTION.

The notable feature in connection with the power supply of a paper mill is the large amount of steam required at several stages of the process, *e.g.*, boiling, digesting, drying, etc. By the obvious method of obtaining this steam from pass-out turbines, the thermal efficiency of the plant may be raised to nearly 65 per cent, as compared with the 30 per cent of a large modern power station.

In Mallinson's paper[2] the author, writing during the transition period between main steam engine drive and centralized generating plant, stressed the advantage of the latter policy, and also that of employing a separate motor for each drive. His arguments are fully accepted by the present authors ; to-day it is the practice among the most progressive mills to install their own centralized generating station and to drive the various machines by means of individual electric motors.

To reap the above advantages it is essential for the paper mill to be self-contained. A typical plant nowadays would embody geared turbine units of about 2,000–3,000 kW, arranged to pass out the necessary process steam, the choice of pressure and superheat being determined by the quantity ratio between power and process requirements. The most economical pressure will be that which enables the steam plant to give all the power required, at a steam flow which satisfies the process and heating needs. The economics of this choice are fully dealt with elsewhere.[6, 7]

With more efficient methods of utilizing the drying steam and by increasing the use of electric power, the tendency has been towards a reduction in quantity of steam generated and, to maintain the balance, for boiler pressures to be increased. Boiler pressures of 350–500 lb. per sq. in., and even higher, are fairly common. The power-house and boiler-room practice closely follows that of modern power stations, load factors of 80–90 per cent being obtained.

In some of the smaller mills a satisfactory compromise has been achieved by retaining a direct rope drive from a geared turbine which also drives a generator to supply auxiliary power and lighting.

An idea of the average requirements can be gathered from Table 1, which includes steam for heating buildings, hot-air plant and the dryers of the paper machine.

The pass-out pressure is settled by the pressure at the dryers, plus an allowance for pressure-drop in the pipes. The temperature of the hottest part of the dryers should not exceed 200 degs. F., otherwise the paper is scorched and the life of the felt is shortened. With a temperature-drop of 40 deg. F. between steam and paper, this implies that the pass-out steam conditions at the turbine should give a pressure of 5–15 lb. per sq. in., saturated or with less than 50 degs. F. superheat, to cover pipe losses. Although superheated steam has a larger heat content its use is objectionable,

as the drying temperature varies between the superheated and saturated temperatures with constant pressure. Moreover, this variation would tend to establish itself between the ends and middles of the dryer cylinders, resulting in uneven drying across the face of the dryer.

rated cables do not cause excessive voltage-drops.

(*c*) The capacity of individual generating sets rarely exceeds 5,000 kW and is usually about 2,000 kW. In these powers the sets may be either alternating or direct current and in either case will be geared.

TABLE 1.

**Average Air, Water, Steam and Power Requirements for Paper Mills per Ton of Paper.**

| | Rag papers | Esparto papers | Newsprint |
|---|---|---|---|
| Steam for drying and heating (5–20 lb./sq. in. gauge) | 3.5–4.5 tons | 3.5–4.5 tons | 3.5–4.5 tons |
| Steam for cooking and recovery (50–60 lb./sq. in gauge) | 2.5–3.0 tons | 4.5–5.0 tons | — |
| Water (100–150 ft. head) .. .. .. .. | 350–400 tons | 300–350 tons | 150–200 tons |
| Air (4–10in. water gauge) .. .. .. .. | 50–65 tons | 50–65 tons | 100–150 tons |
| Power for preparation plant .. .. .. .. | 800–1,000 kWh | 450–500 kWh | 150–200 kWh |
| Power for paper machine drive.. .. .. .. | 50–70 kWh | 50–70 kWh | 90–100 kWh |
| Power for paper machine pumps and auxiliaries .. | 120–180 kWh | 120–180 kWh | 150–200 kWh |
| Power for finishing room .. .. .. .. | 15–20 kWh | 15–20 kWh | 60–100 kWh |
| Power for cranes, conveyors, etc. .. .. .. | 20–25 kWh | 25–30 kWh | 35–50 kWh |
| Power for lighting .. .. .. .. .. | 6–10 kWh | 8–10 kWh | 8–10 kWh |

Mills manufacturing fine papers require additional steam for boiling rags or grass and for operating the recovery plant. For this purpose double pass-out turbines are often installed, the high-pressure steam being used to finish off the boiling process at about 300 degs. F. Small mills employ a single pass-out turbine with a desuperheater to condition steam for the dryers. The pass-out pressure is about 20 to 30 lb. sq. in. and the cooking process is finished off with live steam.

A heat balance sheet for this arrangement, as compared with the double pass-out system, is given in Table 2.

**Electrical Power System.**

The choice between A.C. and D.C. supply and the size of power plant are settled by the type of mill. The systems cannot be standardized, for various reasons, some of which are given below.

(*a*) Mills in which electric drive was employed originally were usually equipped with a D.C. system to which extensions were added from time to time. When reorganization was considered, the loss of production plus the cost of replacement, made it difficult to justify the changeover to alternating current on economic grounds.

(*b*) Paper mills are necessarily compact, owing to the large amount of steam which has to be distributed. This also dictates the placing of the power house as near the centre as possible, so that cable runs do not exceed 200 yards. In consequence, low-voltage power distribution is feasible, and normally-

(*d*) Whichever system is employed, the voltage is about 440, this being limited by the humid conditions under which much of the plant is operated. Since the issue of British Standard Specification No. 116—1937 and the consequent reduction in switch ratings, mills requiring more than 2,500 kW are forced to higher voltages such as 3,300 or 6,600, in order to get adequate rupturing capacity. As these voltages cannot be applied to motors of less than 75 h.p., transformers have to be installed to give 440 volts.

Direct current at 440 volts is more or less free from this disadvantage, as at this voltage plant capacity up to 10,000 kW can be handled by standard types of circuit breaker.

(*e*) Mills are of two categories, (1) those making newsprint or similar paper, and (2) those making a variety of grades in small lots.

In category (1) the output is constant and most of the machinery is run at constant speed. The only exceptions are the finishing sections and the paper machine, which require to possess variable-speed characteristics, representing about 20 per cent of the total power. In such cases A.C. drive is very suitable, and speed variation where needed may be furnished by commutator motors or (if D.C.) from Ward-Leonard sets.

In category (2) the variety of papers calls for variation in output from different machines, and variable speed is essential for at least 50 per cent of the drives. It is also maintained by some paper makers that a speed variation is desirable even for such drives as beaters and refiners. This would allow of the speeds

being adjusted to give the best result from each operation, but it is the authors' experience that such plant is run at full speed continuously, thus involving extra wear and tear, and greater power consumption than is necessary.

In some cases to meet the above conditions a mixed generating set has been installed, consisting of A.C. and D.C. generators with common turbine. The main difficulty is to determine the best capacity ratio between the two supplies, and often, owing to changes in manufacturing process, it is found that the ratio selected no longer holds good. Surplus generating plant of one supply can only be transferred to the other by installing extra converting plant. A cheaper and more efficient method is to use a single A.C. generator and install pumpless rectifiers for the D.C. part of the load. These can be obtained in compact self-contained cubicles up to 500 kW capacity and can be placed conveniently to the point of D.C. power. A view of a steel pumpless rectifier (500 kW at 440 volts) is shown in fig. 3. The advantage of the rectifier

TABLE 2.

**Heating Requirements for Cooking and Drying Steam for Esparto Pulp, supplied by Double Pass-out Turbine and Single Pass-out Turbine.**

| No. | | Double pass-out turbine | Single pass-out turbine |
|---|---|---|---|
| 1 | Heat required for cooking, B.Th.U. | 2,310 | 2,070 |
| 2 | Pressure at turbine stop valve, lb./sq. in. abs. | 215 | 215 |
| 3 | Temperature at turbine stop valve, °F. | 638 | 638 |
| 4 | Heat per lb., B.Th.U. | 1,346 | 1,346 |
| 5 | Pass-out pressure for cooking, lb./sq. in. abs. | 65 | 45 |
| 6 | Heat at cooking pressure, B.Th.U. | 1,230 | 1,195 |
| 7 | Heat drop, B.Th.U. | 116 | 151 |
| 8 | Turbine efficiency, per cent. | 70 | 70 |
| 9 | Heat utilized as power, per lb., B.Th.U. | 81 | 105.5 |
| 10 | Temperature of steam at pass out, °F. | 457 | 404 |
| 11 | Saturated temperature at pass out, °F. | 300 | 274 |
| 12 | Heat in pass-out steam, B.Th.U. per lb. | 1,265 | 1,240.5 |
| 13 | Heat in pass-out steam available, B.Th.U. per lb. | 965 | 966.5 |
| 14 | Steam for cooking (1 ÷ 13), lb. | 2.39 | 2.14 |
| 15 | Total heat utilized as power (9 × 14), B.Th.U. | 194 | 226 |
| 16 | Live steam to finish cook at 300°F. (8.4 + 2.14)26 × 1.1 B.Th.U. | — | 300 |
| 17 | Heat available in live steam (1,346—300), B.Th.U. | — | 1,046 |
| 18 | Live steam, lb. | — | 0.29 |
| 19 | Heat for drying 1 lb. of paper 70 per cent moist, B.Th.U. | 3,400 | 3,400 |
| 20 | Pressure of drying steam, lb./sq. in. abs. | 22 | 45 |
| 21 | Temperature of drying steam, °F. | 313 | 365 |
| 22 | Heat drop in turbine, B.Th.U. per lb. | 206 | 151 |
| 23 | Heat utilized as power, B.Th.U. per lb. | 144 | 105.5 |
| 24 | Heat in drying steam discharge at 230°F., B.Th.U. per lb. | 972 | 1,010 |
| 25 | Steam for drying 1 lb. of paper (19 ÷ 24), lb. | 3.49 | 3.4 |
| 26 | Total heat utilized as power (23 × 25), B.Th.U. | 504 | 359 |
| 27 | Total steam for cooking and drying, lb. | 5.88 | 5.83 |
| 28 | Total heat utilized as power (15 and 26), B.Th.U. | 698 | 585 |
| 29 | Total energy obtained, ft.-lb. | 543,044 | 455,130 |
| 30 | Total heat input (4 × 27), B.Th.U. | 7,914 | 7,847 |
| 31 | Total heat utilized (1, 16, 19 and 28), B.Th.U. | 6,408 | 6,355 |
| 32 | Thermo-dynamic efficiency (30 and 31), per cent | 81 | 81 |

With yield of 42 per cent . . . . . 2.4 lb. esparto grass required for 1 lb. pulp
Liquor to cook grass . . . . . 7.6 lb.
Total weight . . . . . 10.0 lb.
Temperature of cooking process . . . . . 300° F.
Initial temperature of liquor and grass . . . . . 50° F.
Specific heat of grass . . . . . 0.33
Specific heat of liquor . . . . . 1.0
Heat to produce 1 lb. of pulp at 300° F. = (2.4 × 0.33 + 7.6)250 = 2,100 B.Th.U.
Conveyance and radiation losses (10 per cent) . . . . . 210

Total 2,310 B.Th.U.

Boiler pressure 250 lbs./sq. in. abs., 250 deg. F. superheat. Total temperature, 650° F.

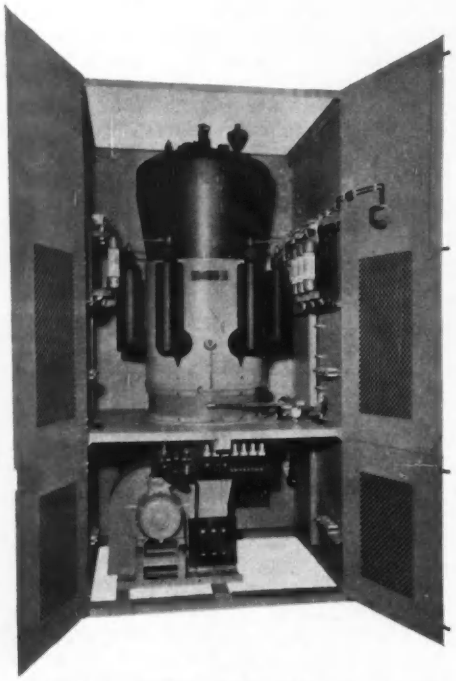

**Fig. 3.—Steel pumpless rectifier (500 kW at 440 volts).**

over rotating converters is the higher efficiency over the whole range and smaller maintenance costs. A full description of power rectifiers has already been published.[21]

Under variable speed conditions the D.C. motor is rather more efficient than the corresponding induction motor, and it is cheaper in first cost than the corresponding A.C. commutator motor.

For a plant capacity of about 5,000 kW the D.C. system appears to be the more suitable. The question of power factor hardly arises, for the mill works under more or less constant load all the time, and with correctly powered plant the overall power factor may easily be maintained at 0·85. First costs of the two systems are about equal if cabling be taken into account.

From the above considerations it will be seen that no hard-and-fast rule can be given as to the choice of system, which is largely influenced by the class or classes of paper to be manufactured.

**Motors.**

Motors have to be liberally rated and soundly constructed as they have to work about 132 hours a week in a humid atmosphere which may be contaminated with chlorine. The enclosure should be drip-proof and able to protect the machine from falling water or a carelessly used hose.

Opinion among users differs greatly as to the best type of bearing. Some mills insist on ring-oiled journal bearings throughout on the grounds of familiarity and the ease with which wear can be observed and dealt with, in contrast with ball or roller bearings where the first intimation of trouble may be a complete breakdown. In the authors' opinion ball bearings are preferable in the smaller sizes, while journal bearings find their best application at the other end of the scale.

The direct-current motors are either shunt-wound or (more usually) compound-wound and are designed to give heavy starting torques. The alternating-current motors are induction machines when the drive calls for constant speeds or small speed variation. For larger speed ranges commutator motors are employed. Carnegie[8] gives characteristics of various drives and types of motors.

In many cases motors have to provide a starting torque several times in excess of full-load torque, and this must be borne in mind

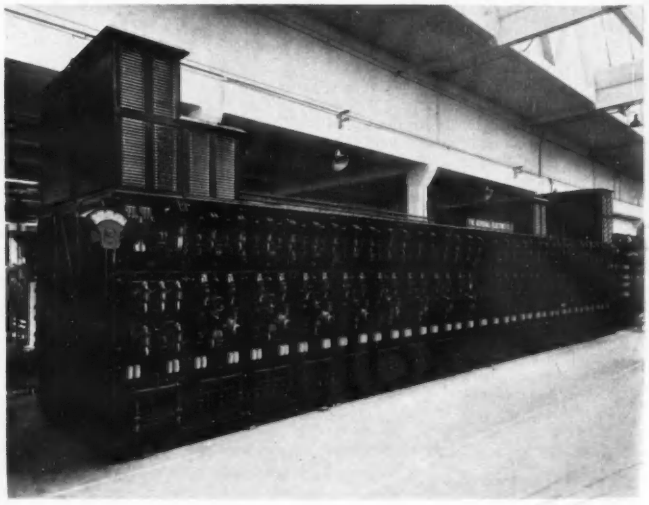

**Fig. 4.—Plural starter switchboard.**

when selecting shafts, couplings, and reduction gears.

**Switch and Control Gear.**

While the generator switchboard in a paper mill does not differ fundamentally from similar installations elsewhere, the handling of relatively large powers at low voltages calls for careful design. Currents are heavy, and potential short-circuits are so high that, in some cases, the power plant must be sectionalized in order to bring the overload protection within the capacity of normal apparatus. In large D.C. installations the possible short-circuit current is particularly difficult to assess, but it is the authors' opinion that this is neither as high nor as devastating as might be expected.

Present practice tends towards the use of air-break circuit-breakers. Large individual

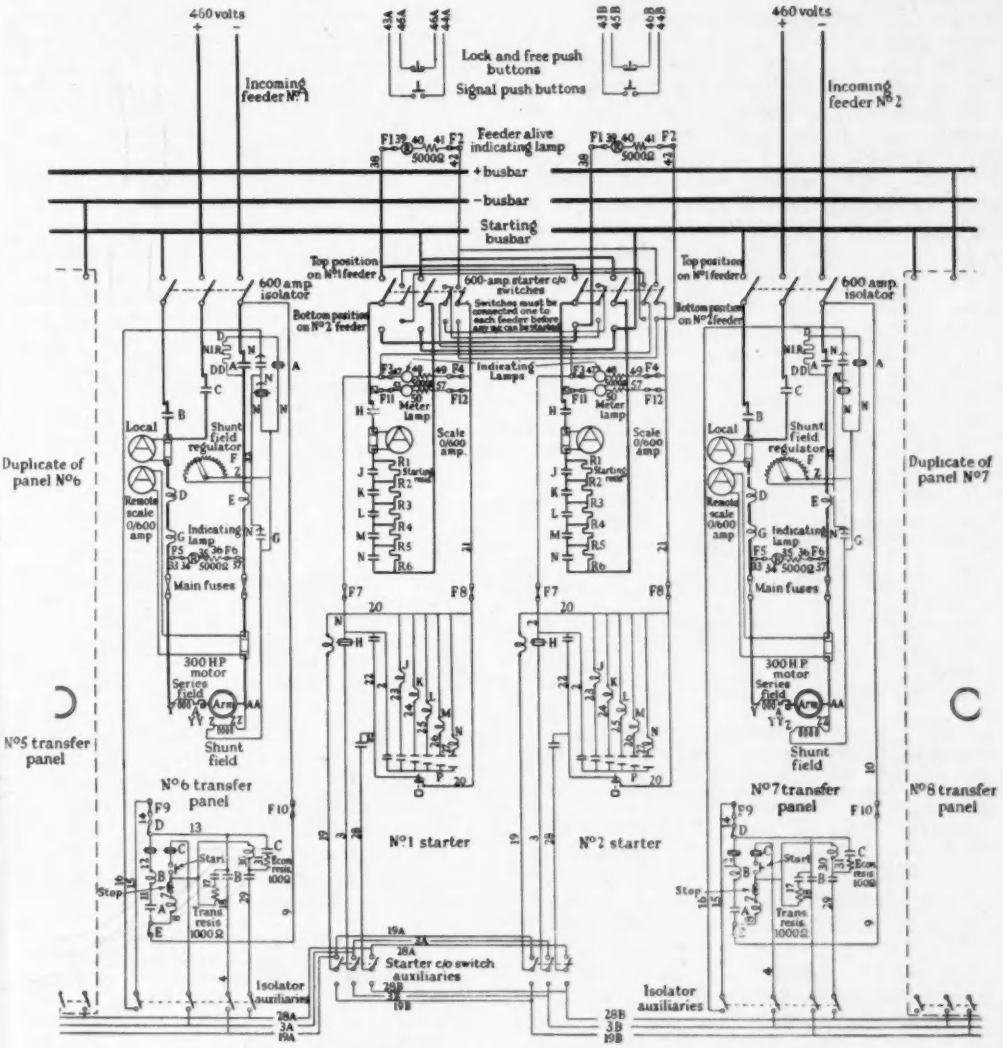


Fig. 5.—Diagram of connections for plural starter.

machines and heavy feeder circuits are sometimes furnished with high-rupturing-capacity fuses as an additional protection. The characteristics of this type of fuse are given by Gibson.[9]

**(3) DRIVES FOR PAPER-MACHINE AUXILIARIES.**

The numerous auxiliaries in a paper mill may be dealt with by more or less standard drives. The mechanical characteristics of the various pumps, beaters and refiners are not especially onerous and the starting conditions do not differ greatly from those found in any other industries.[8]

The auxiliaries immediately concerned with the paper machine itself only require very infrequent starting and lend themselves readily to a "plural starter" system in which a single starter is made to serve a large number of motors. This system was originally developed for marine services where floor space is extremely limited and it has been successfully applied to installations where the smallest motor is only 1/10th the power of the largest motor. A large paper-mill installation is illustrated in fig. 4, while fig. 5 shows the associated connection diagram. From these it will be seen that each motor has a selector panel carrying a pair of line contactors and a starting contactor, together with the necessary overload protection, speed regulators and so forth, a pair of common starters being provided, either of which can be brought into service by means of a selector switch.

The advantages of this system have been found in practice to be as follows :—

(*a*) The starting panel may be housed in an annexe, and kept under skilled observation in clean and dry conditions.

(*b*) A considerable saving is effected in cost of separate starters and resistances and also in their enclosure and protection.

(*c*) The system is easily extended at any time by adding standard panels.

(*d*) Every drive has a standby starter.

(*e*) Maintenance is reduced and simplified.

(*To be continued*).

# Technical Literature.

**A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS BY MEMBERS OF THE G.E.C AND ITS ASSOCIATED COMPANIES.**

**THE SHOT EFFECT IN A SATURATED DIODE.***

**By N. R. Campbell and V. J. Francis (The M.O. Valve Co. and G.E.C. Research Laboratories).**

*Phil. Mag., Vol. 32, p. 239, Sept., 1941.*

Proves by Heaviside analysis that both Campbell's and Shottky's theories lead to the same result when applied to calculate the shot noise in the external circuit of a saturated diode, so long as that circuit consists of lumped impedances.

**NON-LINEAR DISTORTION WITH PARTICULAR REFERENCE TO THE THEORY OF FREQUENCY MODULATED WAVES. PART I***

**By E. C. Cherry and R. S. Rivlin (Research Laboratories).**

*Phil. Mag., Vol. 32, p. 265, October, 1941.*

Explicit expressions are derived for harmonic and cross modulation products in the output current of a non-linear resistive device, such as a thermionic valve, resulting from the application of a wave of E.M.F. This wave may consist of any number of sinusoidal components. The sideband amplitudes of a carrier wave, frequency modulated by any number of sinusoidal components, are derived, and the output current resulting from the application of such a wave to the non-linear device is analysed.

**THE DETERMINATION OF METALS BY MEANS OF 8-HYDROXYQUINOLINE : THE EXAMINATION OF OXINE PRECIPITATES, USING X-RAY DIFFRACTION METHODS.***

**By R. C. Chirnside, C. F. Pritchard and H. P. Rooksby (Research Laboratories).**

*The Analyst, Vol. 66, p. 399, October, 1941.*

X-ray diffraction analysis was used to supplement chemical methods in an investigation of the composition of precipitates formed with 8–hydroxyquinoline and certain metals. Correct drying temperatures to be used in gravimetric analysis were established and the mechanism of co-precipitation of magnesium with zinc, and of aluminium with iron was also investigated.

**SOME APPLICATIONS OF RADIOGRAPHY TO THE ELECTRICAL INDUSTRY.***

**By H. P. Rooksby and K. L. Jackson (Research Laboratories)**

*Journ. Sci. Instruments, Vol. 18, p. 33, March, 1941.*

Some of the ways in which the X-ray technique has been applied in a specific industrial

***A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, B'ham, 6.**

field are indicated. The underlying physical principles are outlined.

**TELEVISION FILM TRANSMITTERS USING APERTURED SCANNING DEVICES.***
**By D. C. Espley and D. O. Walter (Research Laboratories).**
*Journ. I.E.E., Vol. 88, Part III, p. 145, June, 1941.*

Reprinted in the G.E.C. Journal, Vol. XI, p. 266, August, 1941, and on p. 15 of this issue.

**ELECTRICAL DISCHARGES IN GASES AND THEIR APPLICATIONS. PART I.***
**By V. J. Francis and H. G. Jenkins (Research Laboratories).**
*Phys. Soc., Reports, Vol. 7, p. 230, 1940.*

A review of the progress in the study of electric discharges through gases, dealing in particular with those phenomena which have become less obscure either from a descriptive or theoretical point of view. Consideration is also given to the recent advance in the attempts to explain discharge phenomena in terms of atomic processes.

**ELECTRIC DISCHARGE LAMPS.***
**By V. J. Francis and H. G. Jenkins (Research Laboratories)**
*The General Electric Co. Ltd., England, July, 1941.*

A comprehensive treatise on modern electric discharge lamps. Present-day types of mercury and sodium discharge lamps as used for lighting are described in detail, together with the fundamental principles on which they operate. Technical data concerning the lamps and auxiliary apparatus are also included. Operational, installation and maintenance instructions are given supplemented by tables and diagrams. A chapter is devoted to the Osram fluorescent tube.

Much useful data is summarised in the Appendices and an extensive bibliography is included.

**THE YELLOW FLUORESCENT FORM OF ZINC SILICATE.***
**By H. P. Rooksby and A. H. McKeag (Research Laboratories).**
*Faraday Soc., Trans., Vol. 37, p. 308, June, 1941.*

X-ray evidence is presented of the existence of a crystalline form of zinc silicate giving a yellow fluorescence. This confirms Schleede and Gruhl's view that there is a second crystalline variety of zinc orthosilicate.

**SOME APPLICATIONS OF THE X-RAY POWDER METHOD IN INDUSTRIAL LABORATORY PROBLEMS.***
**By H. P. Rooksby (Research Laboratories).**
*Journ. Sci. Instruments, Vol. 18, p. 84, May, 1941.*

Some aspects of the experimental technique of the X-ray powder method are discussed and examples have been chosen to emphasise the diverse character of the problems which have been investigated. Problems connected with the study of refractory materials, thermionic cathode coatings and inorganic luminescent compounds, and some of a metallurgical nature, are discussed.

**STRAY CAPACITANCES; THEIR INFLUENCE ON THE EFFECTIVE INDUCTANCE OF A COIL IN A METAL CONTAINER.***
**By L. I. Farren and R. S. Rivlin (Research Laboratories).**
*Wireless Engineer, Vol. 18, p. 313, August, 1941.*

Formulae are obtained for the effective inductance of a coil in terms of the absolute inductance and lumped stray capacitances when the coil container is connected in a number of different ways. The effects of the stray capacitances of the coils in a "constant k" band-pass filter and in a band-pass crystal lattice filter are discussed and methods of overcoming these effects are given.

**OPTICAL REFRACTION PATTERNS. PART I. THEORY.***
**By R. S. Rivlin (Research Laboratories).**
*Phys. Soc. Proc., Vol. 53, p. 409, 1941.*

Formulae are deduced and curves are given showing the relation between any specified distribution of orientation of small facets uniformly covering a transparent solid medium and the intensity distribution in the refraction pattern obtained by viewing a point source of light through this medium.

**LONG DISTANCE POWER TRANSMISSION BY ALTERNATING CURRENT.***
**By E. Friedländer (Research Laboratories) and C. J. O. Garrard (Witton Engineering Works).**
*Engineering, Vol. 153, p. 1, January 2nd, 1942.*

A simplified treatment of the fundamental problems of long A.C transmission lines, and of their compensation and stability. Various methods of increasing the power limits and stability of such lines are described and their utility examined.

**BRIGHTNESS AND CONTRAST IN ILLUMINATING ENGINEERING.***
**By R. G. Hopkinson, W. R. Stevens and J. M. Waldram (Research Laboratories).**
*Illum. Eng. Soc. (London), Trans., Vol. 6, p. 37, May, 1941.*

This paper was reprinted on p. 246, Vol. XI., No. 4, August, 1941, of the *G.E.C. Journal.*

**A PORTABLE CATHODE-RAY OSCILLOGRAPH.***
**By K. A. Macfadyen (Research Laboratories).**
*Journ. Sci. Instruments, Vol. 17, p. 249, October, 1940.*

A portable oscillograph employing the 4081 monitor tube and an inexpensive cathode-ray tube with a 2½ inch screen is described.

*** A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, B'ham, 6.**

**SOME EXPERIMENTS ON THE SUBSTITUTION OF POTASH IN AN ALKALI-LEAD OXIDE-SILICA GLASS FOR ELECTRIC LAMP PURPOSES.***

**By J. H. Partridge (Research Laboratories).**

*Soc. Glass Technol. J., Vol. 24, p. 151, June, 1941.*

The experimental work involved before a change in the composition of a well established commercial glass can be made with a reasonable chance of success is described and illustrated by reference to alterations made to a lead-oxide glass to meet war-time conditions. In this connection strontium oxide has proved to be a useful glass making material and the properties of glasses containing up to 6 per cent strontium oxide are described.

**AMPLIFIER CHARACTERISTICS AT LOW FREQUENCIES.***

**By G. W. Edwards and E. C. Cherry (Research Laboratories)**

*Journ. I.E.E., Vol. 87, p. 178, 1940.*

This paper deals with frequency characteristics of tetrode, pentode and triode amplifiers as determined by the impedances of the electrode supply circuits and interstage coupling circuits. Methods of complete compensation of the frequency characteristics due to these circuits are developed for single stages or single coupling circuits. These cases are of particular interest in the output stages of television receivers where the D.C. component of the signal is required.

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**ELECTRICITY IN PAPER MILLS.**

**By W. J. Mason and S. A. G. Emms (G.E.C. Engineering Department).**

*Journ. I.E.E., Vol. 88, No. 5, Pt. II., p. 467, October, 1941.*

The first part of this paper is reprinted on p. 51 of this issue of the *G.E.C. Journal*.

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**ESTIMATION OF THE RE-STRIKING CHARACTERISTICS OF SUPPLY NETWORKS.**

**By J. S. Cliff (Witton Engineering Works).**

*Engineer, Vol. 172, pp. 75—77, August 1st, 1941.*

The article explains the importance of re-striking voltage and describes the various methods for evaluating its rate of rise, which decides the severity of the task which a circuit breaker has to perform.

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**THE CATHODE RAY OSCILLOGRAPH IN INDUSTRY.**

**By W. Wilson (Development Laboratory, Witton).**

*BEAMA. J., pp. 58 and 77, April and May, 1941.*

The reason for the considerable advances in the design and application of the cathode ray oscillograph in the engineering industry are considered, followed by a description of the main and auxiliary components of the instrument itself. The various alternative forms of these are described, and compared, and the advantages of each are given. Two diametrically opposite types of oscillograph are considered for purposes of illustration. Short references to the various uses of the instrument in engineering are included.

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**DISTANCE PROTECTION OF FEEDERS.**

**By W. Wilson (Development Laboratory, Witton).**

*BEAMA. J., pp. 91 and 107, June and July, 1941.*

When it has been impracticable to run pilot channels of any description, distance or impedance protection is the standard method of safeguarding single feeders. The principles involved are stated and the various systems of distance protection in use on the Continent, in the United States and in this country are described. The advantages of this method are compared with the other schemes for feeder protection.

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**HEAVY CURRENT TESTING.**

**By W. Wilson (Development Laboratory, Witton).**

*Electrical Engineer and Merchandiser (Australia), p. 31, May, 1941.*

The purpose of heavy current tests on conductors and switchgear is considered, and a brief description given of the historic tests made by Torchio in the United States upon the rigidity of oil switch contacts. The performance of heavy current tests at low voltage are described with details of the apparatus employed. Tables indicating the current carrying capacity of various types of conductor and isolating switch are included.

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**LIGHTING AND RECONSTRUCTION.**

**By R. O. Ackerley (Illuminating Engineering Department).**

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The fundamental principles to be considered in post-war lighting are summarised and an indication given of the technical and administrative problems that may arise. The possibilities of standard specifications for typical classes of buildings are discussed and a method of approach to the problems is suggested.

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